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Royal Aeronautical Society
Journal

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Edited for the
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by
J. Laurence Pritchard, Fellow.

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All communications should be addressed to the Editor.

No. 133.

JANUARY, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on Friday, December 16th:—

Associate Fellow.—O. E. Simmonds, B.A.

Students.—A. O. Adams, F. G. Kay, T. H. Smith.

Members.—V. S. Gaunt, D. Woods Mason, Captain F. H. Parkes-Warmington.

Research in Aeronautics.

The Council have had several discussions on the question of the furtherance of Research, as distinct from *ad hoc* experimentation in aeronautics; three special meetings having been held for this purpose. As a result it has been decided to send a deputation (consisting of the Chairman (Colonel M. O'Gorman), Dr. L. Bairstow, Sir Mackenzie Chalmers, Professor Melvill Jones and Colonel A. Ogilvie) to lay the views of the Council before the Air Ministry. The Secretary of State for Air has consented to receive this deputation at 11.30 a.m. on January 17th.

Airship Records.

On the closing down of experimentation with airships the Air Ministry, as was announced in a previous number of the JOURNAL, decided to present certain books of airship photographs to the Society for safe custody and purposes of record. These books, to the number of nine, have now been received and placed in the library. They should prove of great interest to members as they constitute a complete record, with considerable constructional details, of the development of British airships from 1907 to the present date.

Juvenile Lecture.

Major D. C. M. Hume has consented to deliver the Annual Juvenile Lecture at 3.0 p.m., on Thursday, January 12th, in the Theatre of the Royal Society of Arts, John Street, Adelphi. He will talk on "Boats that Fly," and members may obtain tickets for the children of themselves and their friends on application to the Secretary.

Joint Meeting.

The Illuminating Engineering Society have arranged a meeting at the Royal Society of Arts, Adelphi, at 8.0 p.m., on Tuesday, January 31st, when Major-General Sir Frederick Sykes will take the chair at a discussion on "The Use of Light as an Aid to Aerial Navigation," to be opened by Lieutenant-Colonel L. F. Blandy, D.S.O. At the request of the Illuminating Engineering Society this Society have agreed to treat this as a joint meeting, and it is therefore hoped that as many members as possible will be present. The Secretary will be grateful if any member who wishes to take part in the discussion will kindly inform him.

Associate Fellowship Examinations.

At a meeting of the Candidates' Committee held on Tuesday, December 6th, 1921, a letter from the Honorary Secretary of the Students' Section was discussed and the following recommendations to Council were made. They were subsequently considered by the Council and adopted *in toto*.

1. That it be agreed that Students admitted for the regular engineering course in a college of university standard shall generally be regarded as exempt from Part I. of the examination for Associate Fellowship.
2. It is not to be understood from the note to the Rule given on page 2 of the Rules for Election to Fellowship and Associate Fellowship that attendance throughout an approved course of Aeronautics will *necessarily* be counted as equivalent to one year's experience of the science of aeronautics.

The flying or technical service during the war of any applicant for Associate Fellowship must be considered by the Candidates' Committee on its individual merits. This does not make any specific distinction between flying service during the war and at any other period.

3. It is recommended that the Diploma of East London College in Aeronautics and Aeroplane Design be accepted as exempting from the paper in Aerodynamics under the Rules of the examination for Associate Fellowship of the Society.

Arrangements for the Month.

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| Jan. 5, | 5.30 p.m. | Lecture by Wing-Commander W. D. Beatty, C.B.E., A.F.C., on "Specialised Aircraft," Royal Society of Arts, Adelphi, London. |
| ,, 12, | 3.0 p.m. | Juvenile Lecture, Major D. C. M. Hume on "Boats that Fly," Royal Society of Arts, Adelphi, London. |
| ,, 17, | 11.30 a.m. | Deputation to Secretary of State for Air. |
| | 4.0 p.m. | Candidates' Committee. |
| | 4.30 p.m. | Publications and Library Committee. |
| | 5.0 p.m. | Council. |
| ,, 19, | 5.30 p.m. | Lecture by Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E., on "Aeroplane Installation," Royal Society of Arts, Adelphi, London. |
| ,, 23, | 8.0 p.m. | Lecture by Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E., on "Aeroplane Installation," Royal Technical College, Glasgow. |
| ,, 26, | 7.0 p.m. | Students' Discussion Meeting, Mr. Colin Daniel on "Some Practical Points in Fuselage Construction," in the Society's Library. |
| ,, 31, | 8.0 p.m. | Joint Meeting with the Illuminating Engineering Society. |

W. LOCKWOOD MARSH, *Secretary*.

PROCEEDINGS

THIRD MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, on Thursday, November 17th, 1921. Lieut.-Col. O'Gorman presided.

The CHAIRMAN said that Colonel Frank Searle, who was to read a paper on "The Requirements and Difficulties of Air Transport," needed no introduction to the meeting. They were all well acquainted with him by reputation. He therefore called on Colonel Searle to read his paper.

THE REQUIREMENTS AND DIFFICULTIES OF AIR TRANSPORT.

The subject on which I propose to address you to-night is certainly one with which this generation is not only rightly challenged, but one with which one could almost say that it should be taunted. For nowadays we pride ourselves on the fact that no great invention can be universally acknowledged to be successful without its being very rapidly turned to the economic service of mankind. But aviation has been a human accomplishment for more than half a generation, and so far no aeroplane has earned its cost and keep.

In the old days, when manufactures were primitive, when accurate machine tools did not exist, when very few people were interested or instructed in scientific things and no means existed for instructing or interesting the many, it was natural enough that great inventions should have been made and then allowed to expire, so to speak, without being used.

My historical friends tell me that the great Marquis of Worcester, in addition to many inventions which never materialised, did actually instal a complete water supply at his country house, and pumped the water from his well to the tank which supplied the house by means of a steam engine. What the Marquis of Worcester could do before the end of the 17th century remained unique and unimitated until steam was rediscovered more than a hundred years later. It was then applied first to actuating machinery, and then to actuating the paddles of a ship, and finally to actuating the wheels of a locomotive. But once the first railway had been shown in operation, the expansion of the railway service was both rapid and universal. Similarly, when it was shown that an internal combustion engine could be made to drive the wheels of a car for use on the roads it was a comparatively short time before the progress of the automobile industry was limited only by the time it took for manufacturers to learn the business of engine and car manufacture. But it is not very far from twenty years now since the first aeroplane propelled by an internal combustion engine was made to fly. The science and the art of aviation received an incredible impetus during the war, and now after three years of peace we have sorrowfully, and perhaps shamefacedly, to acknowledge that we have not yet overcome and mastered the problem of serving mankind by air transport. But, like every other phenomenon, at first glance startling, there is an explanation of this failure, or if you prefer to call it so, the very qualified success of civil aviation. It is our business to end this failure, to complete this success; and I suggest that the right way to begin is to visualise as clearly as we can what are the essential characters of the problem, because when we have analysed and stated these we shall see clearly what the obstacles are to their being practically met.

These requirements are obviously of three kinds. First there are those proper to the vehicle you propose to employ; these group themselves naturally into the requirements of the engine, as a source of power, and the plane, both as a device for rising into the air, staying in the air, and descending from the air to the land in a satisfactory way; and as a commodious and pleasant vehicle for the accommodation of travellers. Next, bearing in mind that it is a question of transport we are considering, there are all the problems involved in bringing travellers from their homes to the flying machine before it starts, and delivering them from the flying machine, after it has arrived, to their final destination. And lastly—and it is these requirements which govern the whole problem—there is the question of giving that rapidity and certainty of service to the customer at a price which he recognises to represent the advantages offered, and this without the apparatus and the organisation costing more than the travellers are able to pay. Stated in another way, then, the requirements fall into three groups which should be called the technical group, the organisation group, and the economic group.

Now it is my belief that all these requirements can be met, and I base that belief on a considerable experience of transport in other fields, and by some experience, not long but very instructive, in the field we are discussing to-night, and as I have suggested, the first condition is to state what the requirements are, and from these we shall see from past experience why they have not been met before.

The ideal aeroplane for civil transport must consist of an engine on which the undertakers of the transport service can rely, not only for steady work, but for long work at a reasonable maintenance cost. The vehicle it propels must take the maximum load with the maximum comfort, the limitation in each case being the speed, certainty and safety, without which air transport can never become a commercial success. And the cost and upkeep of both must be reasonable.

Our three years' experience of civil flying since the war show us that there is not in universal use to-day the engine which meets the requirements I have set out. The explanation is not so much that these requirements have not been understood as that at the time when civil aviation became for the first time a possibility, the argument for experimenting with makeshift gear was irresistible, the attitude of directors and others in aircraft manufacturing firms soon after the time of the Armistice when they, in moments of apprehension, turned their minds to air transport. This apprehension must have been genuine and severe, knowing that the Government aircraft orders were ceasing and that something would have to be done, and done quickly, if the huge factories were to exist even on a much smaller scale.

When some of these firms turned their energies to aerial transport one had got to visualise the composition of these companies in order to see whether they were in any way competent to carry through to successful issue aerial or any other form of transport.

It must be borne in mind that at the beginning of the war the science of aviation was so young and the necessity for aircraft so great that both the management and the technical staffs of aircraft manufacturers were intensive productions, and from the beginning of the war to the end of it, were fostered on expensive lines; whilst at the same time the managements and technical staffs of other and more slowly-developed industries were all fully occupied and necessary in their own particular sphere.

Another very great factor was that these intensive staffs were reared in an atmosphere of forced production with very little regard for economy either in personnel or material. It is not very surprising, therefore, that when they made their momentous decision to go into aerial transport they went ahead on what to them was their ordinary business methods, namely, of extravagance in men and material, and, instead of enlisting new men and material, carried on with what existed at the moment.

Their first thought seems to have been to transfer war machines and men to the transport companies, the majority of both being not only unsuitable but detrimental to the very progress they were so anxious to foster. The designers, too, who are the aerodynamic and theoretical people on whom we rely for flying efficiency, had not the advice of people with practical transport experience to guide them as to the requirements of a commercial transport service; they had only the advice of those whose experience was limited to war flying. The tendency of the designers themselves, quite naturally, was also influenced by their experience having been gained, one might almost say entirely, in the design of machines for war purposes. My critics will no doubt say that it is easy to be wise after the event, but if we examine the problem they had to solve it will be admitted that any authority on transport for profit would have provided different men and different machines.

A transport man would have at once gone into the daily overhead charges per machine, in which would be included such ordinary items as depreciation, insurance, interest on capital and management and office charges, and these, plus the net flying cost per mile, would give clearly the number of miles per day per machine which have to be flown in order to break even, assuming the average normal load of other forms of transport.

In spite of the ease with which such figures could have been obtained, at the time I went into business (which was twelve months after air transport had been established) I was told by one of the highest authorities on flying—a man who had gained a very high reputation during the war, but who had only war experience and no commercial experience—that an aeroplane could only fly 250 hours a year. This means approximately 70 miles per day; therefore, at 50 per cent. load, a four-seater machine, charging 1s. 6d. per mile per passenger, could not possibly earn sufficient to pay its overhead charges—this figure represents an £18 fare to Paris, at which price passengers could not be obtained. Nor could they be obtained at £15. At £10 they began to appear in small numbers, and at £6 we find signs of real interest. In addition to this, not having worked out and appreciated these fundamental figures, firms employed a far greater number of machines than were necessary to obtain even the above unsatisfactory figures. On the other hand, one must not lose sight of the fact that but for their heroic efforts and the colossal loss of their, and other people's, money, civil aviation would not be where it is to-day; though had they found the money and given the problem to some firm who had been successful for many years in mechanical transport, it could have been to-day on a much sounder basis than it is.

The operation and maintenance of their machines was carried on with lamentable lack of knowledge. For instance, whilst they employed a vast number of machines for the services which were maintained and on which the overhead charges went on daily, there was a very serious shortage of spare parts and spare engines, and, in consequence, machines were lying idle whilst their engines were being repaired, which meant that they were not only losing their earning capacity but that the overheads of about £4 per day per machine were going on for two or three weeks.

Again, little or no equipment was provided for doing repairs and inspections expeditiously, whereas a small capital outlay in this direction would have saved hundreds of pounds in labour.

Again, none of the executive heads of the concerns held ground engineers' tickets as granted by the Air Ministry. These were all held by mechanics, so the decision as to fitness or otherwise of a machine was in the hands of the workmen, whose word was final. It should, of course, have been imperative that those in charge held the necessary qualifications required by the Air Ministry.

In addition to this, the facilities for carrying on one's work at Croydon were very poor since in many cases the machines of various companies were mixed up

in one shed and machines had to be constantly moved about in order to accommodate others arriving at odd times. Also, no bulk petrol storage tanks were provided, which meant that big quantities of petrol had to be man-handled in two-gallon tins, whereas a little forethought would have saved all this labour and at the same time saved $1\frac{1}{2}$ d. per gallon on the price of the petrol which, considering the quantities consumed by aeroplanes, amounts to a considerable sum at the end of a year. The Air Ministry had considered the bulk storage question, but had shelved it owing to the fact that during the next three years they might have had to shift it to a more permanent spot. I mention this to show that the people handling air transport at this time were lacking the commercial touch, since in this case an expenditure of £500 would have saved £750 the first year.

Again, at this period the meteorological information was mostly too late and too meagre to be of real service, and the wireless installations were very ineffective. It was the same with the Air Ministry as it was with the companies—they had not the experience to differentiate between the essentials and non-essentials of air transport, and consequently often spent money unwisely from this standpoint. One must admit that the Air Ministry worked exceedingly hard in the interests of air transport, but they were guided by chance and not by experience, and I feel sure there must have been someone in the marine or road transport business who could have given them the guiding principles of their own business which would have been useful in air transport.

In the past the air transport companies were in the habit of carrying all their passengers and goods to and from the aerodrome (which cost them over £1 per head or 10 per cent. of the fare), and also of giving 10 per cent. commission to the various travel offices for booking a passenger by air. This again is excessive, and such offices should not expect more from air companies than from railway or steamship companies; in fact, in order to foster the business, they should be prepared to accept less. It is these heavy unnecessary charges that must go, otherwise air transport must fail.

Now with regard to air passenger organisation. The circumstances proper to all other forms of transport are proper to transportation by air. Nobody would make a success of the finest and fastest Atlantic steamer service that science can conceive or genius supply if the rapid and luxurious ships, we suppose in existence, started from some inaccessible port in England and arrived at some destination in America extraordinarily inconvenient to those who wish to go to the centres of population. It is not a counsel of perfection; it is simply axiomatic that the aeroplane, like the express train and like the steamship, is not a self-sufficient vehicle as, for instance, is the motor car. To get to the train you have to use a carriage or car to take you to the station; when you arrive at your train destination you have to have another vehicle to take you home. If you leave England and live in London you have to take a train to the port from which the ship starts. If you arrive in New York and your destination is Chicago, you have to take a train from New York to Chicago. In the first case the carriage and the cab, and in the second case the train service, are integral factors in the journey. Now so far as civil aviation is concerned, we have neither in England nor in Paris a starting and landing point for aeroplanes which is served by cheap, commodious and punctual train services; for that matter they are not served by train services at all. Secondly, to go back to our first comparison. If you are going from London to Liverpool, and thence from Liverpool to New York, you can drive in a closed carriage to Euston where there is a comfortable station and waiting rooms affording complete protection from the weather, and when you get to Liverpool the train runs alongside the steamer, and you go along a covered gangway to the ship. It is only a few years since the trains started running alongside the ships at Liverpool and other ports, but it was realised what an important advance it would be, and how much such a service would add to the comfort of passengers. You can hardly expect the air service to be

as comfortable as the train service until some such amenities as these exist at the starting and landing place. At present there is no means of getting to the aviation grounds at Croydon at all except by car, and arrived there, there are neither waiting rooms nor conveniences of any kind for the comfort of the passenger, and he has to walk many hundreds of yards, often through slush and mud, before he reaches the vehicle in which he is to spend two hours nursing his sodden feet to Paris.

I mention only the rudimentary shortcomings of the air service as it exists to-day, but obviously we cannot hope for flying to be a regular feature of normal travelling life until this form of travelling includes—I will not say the luxuries—but these mere mitigations of discomfort which we all take for granted when travelling by train or steamer.

And here another point must be considered. One of the fundamental troubles in connection with flying to-day is not only that the traveller has none of the comforts and conveniences that he is accustomed to in other forms of travelling, but he is put to enormously greater expense because of the absence of facilities which surely could be supplied without undue cost or risk. It is, in my opinion, simply absurd that there should not be a regular service of trains to a platform running alongside the plane at the aerodrome, so that within a quarter of an hour of saying good-bye to his friends in London the traveller should be seated in his aeroplane and ready to start; and that there should not exist in Paris a service of exactly the same nature. Apart from all other question, this provision for the comfort of the traveller is an indispensable condition of successful commercial flying.

The question at once arises as to who is going to provide the railway facilities to the aerodrome. In the first place, an aerodrome should not be chosen which is cut off from the outer world either by distance or lack of communication, and if the ideal aerodrome necessitates such glorious isolation, then the Government must subsidise some railway company to provide the necessary connection. But for the Government to choose an isolated spot for an aerodrome and then subsidise air transport companies by a subsidy on gross takings from passengers who cannot get there is, of course, absurd.

Now when it comes to the economic side of flying, this obviously is a question of balance between receipt and costs. The circumstances that define the most economical form of ship or train or motor car are the same as those that define the desired features of an economical aeroplane. The speed must be such as to give an overwhelming advantage over any other form of locomotion. But it must be speed consistent with carrying a considerable load at a running cost which is not excessive, and it must be speed that does not demand either excessive first costs of engine and aeroplane or excessive upkeep. On these points we have learnt a great deal in the last three years, but I venture to say that we should have learnt more if the public authority for dealing with flying had been composed of individuals more familiar with the problems as we see them in this room, and less influenced by experience and problems of a totally different nature, namely, those propounded by aviation during the war.

The position of the Air Ministry in air transport is a most important question, and one which ought to be cleared up at once. At the present moment it combines the equivalents of Municipal Authorities, Trinity House, the Board of Trade and Lloyd's, and I will deal with the analogous functions in this order.

In my opinion the Air Ministry must for the time being continue to act as Municipal Authorities in the way of developing aerodromes, and as Trinity House in regard to navigation, but in carrying out these duties every effort should be made to improve the foreign liaison with our neighbours and persuade them forcefully to provide the same facilities on their customs' aerodromes as we provide on ours, as well as equal lighthouses on the routes. France has had far more money voted to civil aviation than we, and yet Le Bourget and St. Inglevert

are disgracefully organised. The London aerodrome should be at least 1,200 yards square, and the adjoining land should be acquired and let out for grazing so as to provide a good take-off in every direction and provide good re-landing possibilities during that period of flight just after taking off. The sheds should be on the lee-side of the aerodrome to prevailing winds so as to minimise taxi-ing, which is a serious cost, and one which was given very little consideration during the war by reason of the fact that it was not necessary to count the cost; but I have no hesitation in saying that five minutes of taxi-ing does more damage to a machine than ten hours' flying. Separate accommodation should be provided for each company, with a common shed for "casuals."

If the Air Ministry are to continue to act Trinity House, as they must, they must accept the responsibility for persuading adjoining countries to do likewise, so that night flying may be made as safe as daylight flying. On the Paris route there should be two lighthouses between Croydon and Lympne, and three or four between Paris, La Plage and Le Bourget.

In regard to the Air Ministry acting as the equivalent of the Board of Trade and Lloyd's in marine matters, I have no objection to their doing the former's equivalent duties, but with regard to the latter I do feel that the time is here for owners, builders and underwriters to get together and form some sort of Lloyd's Committee so as to keep the Air Ministry advised of their requirements. The question is one of the utmost importance. The Air Ministry has not yet the complete confidence of business men, and it is necessary for them to have some reliable source of information as to what regulations are necessary for the protection of all their interests.

There are some very brilliant young men at the Air Ministry who are most thorough and conscientious in their work; but when one deducts their negative commercial and economic experience of the war, one finds that experience with them cannot be expected. And in a few cases, after deducting their negative war experience, they could not have had more than the meagre engineering or technical training of an apprentice or pupil.

These men in many cases have the power to dictate as to design and details of operation, and companies have no appeal from their considered opinions which are invariably based upon war experience and R.A.F. training. Every official in the technical branches of the Air Ministry should be an engineer of good training and undoubted experience excluding his war service.

I should also like to mention the examinations for ground engineers. These are verbal examinations, and are therefore the most difficult to organise, and from what I have seen, they have a tendency to follow that unsound policy adopted temporarily years ago in some of the Board of Trade examinations for the marine engineers' tickets—it is that of trying to "catch" the applicant by trick questions instead of thoroughly ascertaining his education, experience and knowledge. An example seen in the Air Ministry was a stretching screw—or turnbuckle—which had both ends screwed to the same hand; and the applicant was asked to examine it and state where it was faulty. I suggest that such "catches" are not a reasonable test either for education, experience or knowledge, which all goes to indicate that the examiners do not quite realise the essential qualifications of the holder of such a ticket, and I consider that the examination papers for the applicants for these tickets should be laid down by the committee to which I have referred.

The wireless on this side is good but stronger liaison is required with the Continent, where the wireless service even yet, after two years, is still practically useless, and direction finding must be developed to perfection along the whole of the Paris route without delay.

Some organisation would appear to be necessary for flying in mists and clouds, in that on the organised routes machines flying in opposite directions

should have different ranges of altitudes. This, I think, is where the Committee previously referred to should make some recommendations, and it is most important that the meteorological office should collect information from machines in the air and distribute it within a few minutes, when the information would be of great practical value.

The time must be fairly near when emergency landing grounds will not be required, but I think that for two years more the Air Ministry should maintain two landing grounds between Croydon and Lympne, and they should insist upon the French providing one near Abbeville and another near Beauvais.

I will now turn to the subject of aeroplanes and engines and the first remark I will make is that manufacturers must guarantee their productions for a reasonable period after delivery; the guarantee must include the risk of parts having to be re-designed owing to faulty design in the first place. It is no use a manufacturer selling a batch of engines and after three months admitting that the compression is too high and offering to supply new sets of pistons for £60 or £100 per set; and then after another three months admitting that the connecting rods are of unsuitable design and refusing to replace them except at the cost of over £200. I can only say that those manufacturers who are not prepared to guarantee their goods for the purpose for which they were purchased will be left without orders as soon as opportunity occurs. I am glad to say that there are signs of some manufacturers of machines taking some of the responsibility for their design.

In the interests of aircraft manufacturers I should like to sound a modest note of warning to the effect that they should not let history repeat itself by forcing the air transport companies into manufacturing their own machines, due to high prices, as has been the case with other forms of passenger transport. They must bear in mind that it is difficult for a manufacturer to retaliate, since he must make his machines suitable for as many markets as possible and therefore cannot specialise.

To my mind the price of the present day machine is altogether too high, although efforts seem to have been made to reduce the price. With the present wood construction, which still presents outstanding advantages, I am sure a lot more can be done. The all-metal machine seems as far off as ever, and I doubt very much whether it will ever be nearer than a composite of metal and wood.

Notwithstanding the many times I have expressed my candid views on such questions as engine installation, cowling, controls, etc., I find very little improvement to-day in most of the latest designs of aeroplanes; and the war-type practice in many cases appears to be very deep rooted.

Also there still appears to be a strong tendency in design to put appearance, in the way of pleasing exterior lines, before utility and service. In the design of the various metal clips and fittings on our aeroplane I plead for the use of ordinary commercial mild steel plate, which after working requires only the crudest annealing. In speaking of the propeller, I think that it is time a weather-proof propeller was in transport service. A metal propeller fills the bill if it does not weigh too much or absorb too much power, but I think we are on the wrong lines still trying to use a metal tip on to a wood propeller, which twists and stretches all the time it is working.

The continued use of the pneumatic tyre surprises me. I feel sure that a solid-tyred wheel can be designed which will transmit safely all the shocks and forces to the undercarriage damping gear, and yet not be too heavy. The Germans used wooden tyres during the latter part of the war. My critics will now tell me that they soon changed to pneumatics whenever they could get them. This is true, but one must bear in mind that the German undercarriages are not as shock-absorbing as ours, and the fact remains that the German wheels stood up very well.

On the subject of engines, my chief complaint is the cost of the engine and spare parts. I give a few examples and comparisons. One of the best known modern aeroplane engines costs £6,000 per ton. Complete machinery, including boilers and all auxiliaries, for a 35-knot destroyer costs only £200 per ton. Complete machinery, including boilers and all auxiliaries, for a 25-knot cross-channel vessel costs about £90 per ton. I am told that the reason for the high cost of the aeroplane engine is due to the expensive material and the still more expensive testing and heat treatment. If this is a fact then we must sacrifice 20 per cent. of the engine weight and get down to an article which will appeal to the commercial engineer, an engine which will run 30,000 miles without overhaul, and I am sure that one giving such results could soon be evolved if the type tests for these engines were made on the time table basis. I suggest three 3-hour stretches a day with one hour's interval between, during which time the engine must not be touched; the engine to start at the same hours every day until 300 hours is reached, ten minutes being allowed before the time table time for starting and warming up to full power. The three-hour stretches should comprise 10 minutes at the start at full power, then 75 per cent. full power for the remaining 2 hours 50 minutes. The engine that can stand up to this test, even if its price is not lower than say 25 per cent. below present prices, will fill the bill.

In conclusion, I do trust that those whom I have criticised will accept such criticism in the spirit in which it is made and as coming from one who has had some knowledge of other new forms of transport from the operator's point of view, and in consequence has suffered agonies from the official side and the manufacturer's side, and I wish to see air transport relieved from as much of that nerve-racking experience as possible. My final advice is that you should make your objective the success of aerial transport, forcing through the essentials and leaving the non-essentials until the industry is firmly established.

DISCUSSION.

The CHAIRMAN said that at the appropriate moment he would ask the meeting to pass a hearty vote of thanks to Colonel Searle, but he thought they had better discuss the paper first. He opened the discussion by reading a communication which had been received from Captain de Havilland and he was sure they would like to hear what Captain de Havilland had to say.

"I have read with much interest Colonel Searle's clear and forceful paper. In the main I agree with his remarks. There are a few points connected with design on which I would like to comment. One of the chief difficulties of designing firms has been the time factor. After the Armistice most designing firms were either disbanded or had to reduce their staffs considerably, and could only exist on Government orders for military machines. They could not afford to lay down commercial types on the chance of an order, and it was only a few weeks ago that there was any certainty of orders for commercial machines. And these machines have to be turned out by next spring, embodying all those ideal points mentioned in Colonel Searle's paper. Under these conditions it would be very unwise to strike out on any new line of design. A machine embodying new features requires at least a year and probably more before it can be called 'tried out.'

"I entirely agree with Colonel Searle on the matter of speed and incidentally it is the fact that a high speed machine is cheaper in first cost and maintenance. The landing difficulties of high speed machines have been enormously exaggerated, as proved from actual experience.

"I agree with Colonel Searle that pneumatic tyres are undesirable. I also fully endorse his remarks about metal construction. I can see nothing

but trouble and expense with metal machines as at present designed and firmly believe in the future of wood construction. We want to break away from a lot of convention in construction, and the Air Ministry can help by not adhering to wartime restrictions (such as the absolute prohibition of piano wire, the laying down of close restrictions on petrol and water systems). The specifications for certain materials, such as three-ply and fabric, should be made easier, and every facility should be given for expansion of ideas on design. All this will help to cheapen machines.

“The only pessimistic remark in the paper from the public’s point of view is that ‘The ideal aeroplane for civil transport must consist of an engine on which the *undertakers* of the transport service can rely.’”

Mr. HANDLEY PAGE said he had read through the paper, like everyone else, with intense interest. He had thought of opening his remarks by saying, “Now we know all about it,” because, if he might say so without offence to the lecturer, it was easy to be dogmatic in what are the requirements of civil aviation after one had found them out. One must carry one’s mind back to the early days of civil aviation when the mere thought of running continuously, day by day, no matter what the weather was, between London and Paris, was jeered at by a very large number of people. The initial problem was the serious difficulties in aerodynamics which had to be got over before the super-men, who had had experience in the transport world, could make the undertaking the success which they all looked for, should he say next year? (laughter). He had been extremely interested, apart from this paper, in reading in “The Times” a report of General Trenchard’s speech on civil aviation and whether, in fact, civil aviation was any good to any country. General Trenchard had looked at the matter purely from the point of view of one who was charged with the very high duty of defending our shores against invasion, and he had said that civil aviation, both from the point of view of cost and pilots and men and flying hours, was very expensive compared with the additional squadrons which could be given if the money had been spent on territorial forces. That seemed to him (the speaker) an extraordinary view, because if that was going to be the case, then civil aviation must always be looked at as a background for the military side. He himself was one of those people who thought that the military side of aviation was something which was in the background of civil aviation. The first thing was that the small amounts spent on civil aviation provided just that little difference between a big volume of receipts and the slightly bigger volume of expenditure which occurred in the initial stages. The money wisely spent would thus produce far better results in that particular direction than on a military objective only. Civil aviation might take a most useful analogy from the animal world. He was informed that of all animals the human infant was the most helpless, but when grown and of full size it had the greatest power of vision and the greatest intelligence of all animals, but it required a lot of money in the early stages, and the more sick the infant was, the greater the cost. There was a very good analogy in that for civil aviation. In the early stages it was very costly. If they did not treat it properly and it got sick it became more costly, and the only way was to treat it properly, and then it would grow up and, by its intelligence, far surpass all other means of transport.

He had been extremely interested to read the different qualities which Colonel Searle laid down for an aeroplane which would be successful for air transport. It had been his privilege during the last few days to sit in the conference which had been taking place in Paris and listen—and sometimes understand—what was said, and the conclusion he had come to was that the most successful way of popularising civil aviation was by flying. Far more progress would be made by experimental research through continued flying and finding out the difficulties and the things that had to be overcome than by laying down too definitely at an early stage

what we must do and what we must not do, because he felt the time was hardly ripe yet when we could be too definite in our specifications. In saying that, however, he did not wish in any way to detract from the excellent and lucid way in which Colonel Searle had put forward certain requirements that were necessary and essential to air transport.

Colonel T. F. BRIGGS, called on by the Chairman, said he regretted that he had not received an advance copy of the paper and was not, therefore, in a position to discuss it very fully.

The CHAIRMAN reminded the members that if they would send a postcard to the Secretary an advance copy of the papers would be sent to them. Not being, unfortunately, a rich society, they could not send advance copies around wholesale.

Colonel BRIGGS said the only point that occurred to him was that of silencers, which ought to be given consideration to from the point of view of the comfort of the passengers.

Captain GILLMAN, referring to the mention in the paper of the desirability of a committee of Lloyds being formed, said that such a committee was formed in June, 1920. The members of that committee were composed of underwriters of aviation risks, members of Lloyds' Committee and representatives of aircraft constructors as well as a representative of air transport companies. The committee had been trying, as much as it could, to make the conditions of flying in civil aviation safer and it certainly had met with a fair amount of success. It had sent up various reports to the the Air Ministry and it had also passed certain resolutions which had been circulated, and it was hoped, later on, that the scope of its work would become more and more wide. Among other things, it had created a register of aircraft and pilots; this was the beginning of a register which would resemble Lloyds' Register of Shipping. At the present moment this register consisted of books which merely stated facts about machines without any pretence of classification. Classification had not been tackled because it was a very difficult subject and had got to be approached very carefully, and the committee would much rather go to work slowly but surely. With regard to any recommendations by the committee, it seemed to him that it would be very useful if there was a higher committee formed, which would be a Supreme Council on aviation, composed of Air Ministry officials and representatives of aircraft manufacturers, air transport companies and members of Lloyds. This committee, he suggested, should have plenary powers to pass rules and regulations and make laws to govern civil aviation. It was not satisfactory that when official bodies like the S.B.A.C. and Lloyds send up resolutions, there should be another body which could veto them entirely if it wanted to. Such a system was not right, and corporations like Lloyds and the S.B.A.C. should have some say in the matter afterwards, because very often—he did not say it had happened, but it was quite possible—an important resolution might definitely be shelved. With regard to railways, Croydon seemed to be a favourable place to start from, and if the point of departure was moved to the north side of the aerodrome, near the tram lines, it would only need a short line run from Waddon station to the point of embarkation. As an alternative the L.B. and S.C. Rly. could stop its trains at Waddon at certain times and a conveyance could be provided to take the passengers from the train to the point of departure. As regards grazing on the aerodrome, if ground was to be looked upon as an emergency landing ground, it was very undesirable to permit grazing on it as more than one accident had happened through an aeroplane running into an animal grazing in a field when it was forced to land. If they were going to have land for this purpose, then it should be kept clear for machines. Another point was taxi-ing across the aerodrome. He did not see why a hard track could not be laid down round the aerodrome. It ought not to be a very expensive affair; it need not be ferro-concrete but just sufficiently hard to carry the heaviest machine, and then the

machines could easily be run along the track to a suitable position from which they could take off into the wind. There could also be something in the nature of an electric trolley, to haul the machines tail first to the desired spot. After landing, machines could in the same manner be hauled back to the sheds by the trolley. It would save all vibration and a great deal of petrol and oil. He asked if Colonel Searle would give his opinion as to the possibilities of air transport in Great Britain, including Ireland.

Colonel OGILVIE, whilst endorsing almost everything Colonel Searle had said, thought there were one or two points at the end of the paper on which questions might be raised, especially as regards the figures as to the cost and weight of engines and the possibility of increasing the weight by 20 per cent. The cost figure given was £6,000 per ton. He did not know of any engine in service which cost that, if, as they should, they considered with the engine such parts as the radiator and propeller. On that basis it would be found that the figures given in the paper were not at all correct. It would be found that one very good engine at the present time would come to about £2,000 per ton and another £4,000, and these were both engines which were being used at the present time for civil aircraft transport.

The CHAIRMAN asked how adding the radiator diminished the price per ton.

Colonel OGILVIE replied that while considering the weight of the engine they must think of it as a complete engine unit suitable to function as the power plant of the aeroplane and not simply as the engine stripped of all the parts such as radiator, which were really part of it. The addition of these accessories did not really make a great deal of difference and might make the figure £2,500 instead of £2,000 for the cheaper engine he had mentioned; £6,000 per ton was altogether a terrific price.

He would also like to dispute the "cost per ton" way of looking at engines. What was wanted was an engine as light as possible and not as heavy as possible. On the "cost per ton" basis it would, of course, be a lot cheaper per ton to double the weight of the engine with the addition of lead, but this would not make it a useful engine. A much better way of looking at engines was on the "cost per horse-power" basis.

The two engines he had in mind came out at £3 per h.p. in one case and £5 per h.p. in the other. He had not got any certain knowledge of the cost of a destroyer engine plant, but as far as he could find out, it worked out at about £4 per h.p., which was something very comparable to aircraft engines.

The question of increasing the weight of engines by 20 per cent. was a very important matter. It was easy enough to say that we would like to have an engine which was more reliable and that we could afford to pay 20 per cent. more for it, but actually he very much doubted if we could afford it. If they took an ordinary machine of the present day and worked out the various percentages for the engine unit, the structural unit, the load unit, and so on, it would be found that by adding 20 per cent. to the engine unit they would be knocking off something like one-third or one-quarter of the available paying load. The load percentage was reduced from about 25 per cent. to 18 per cent. and he suggested that that was too much to pay.

Captain HISCOCKS, referring to a point made by Colonel Ogilvie that comparison of aero engines with other prime movers should be made on a cost basis and not on a weight basis, stated that the cost per h.p. in an aero engine was about £5, and that this compared favourably with steam, gas and electric power units as well as with petrol engines used for pleasure and commercial vehicles.

Although at first sight an aero engine looked expensive because its size and weight were relatively small, it should be remembered that the materials used were the best obtainable, the amount of work done on the parts large, the per-

centage of scrapped parts high, a large amount of jigs and tools and special plant was necessary, and the cost of the experimental work was higher than in the case of the manufacture of other kinds of prime movers.

A manufacturer might easily spend £30,000 to £40,000 developing a design of aero engine which theoretically, and on paper, appeared very promising, but which when made would not satisfy all the requirements of a successful aero engine, and it is probable that only one design in a dozen ever gets home and makes a profit.

The case for the aeroplane manufacturers is somewhat similar, and one would like to remind Colonel Searle that for aeronautics to progress and flourish, the manufacturer must make some profit as well as the transport companies.

Mr. GREEN said he came to the meeting knowing little about civil air transport and had hoped to listen rather than to talk. The lecturer's interesting paper reminded him rather of an incident that occurred during the early part of the war, when he was interviewing an official of the War Office in connection with an aero engine. This official told him that it was not a bad engine, that it went all right, but that it was made of materials that were too difficult to get. What he wanted was an engine made of cast iron and not too good cast iron at that. This is a really true story and the speaker could not help feeling that Colonel Searle was working rather on the same lines. Colonel Searle said we must have cheaper and better engines and of course this is what we are trying for. Unless all designers were rather stupid, better engines would no doubt be produced in time.

Colonel Searle had put a great many points forcibly and clearly before them and the speaker was sure they would all profit by the paper. It seemed to him a little dangerous for the lecturer to suggest that we should make heavier engines or heavier aeroplanes, or heavier anything else that was used in aeronautics. The margin of paying load was now very small, and any little addition, such as an increase of 20 per cent. in the weight of the engine, would make it even more difficult to make flying pay, even if the engines ran longer without overhaul. In the speaker's opinion development must be in the direction of lighter engines and lighter aeroplanes. We should have to go on learning and putting better engineering into our work so that we can make a light engine and a light aeroplane last a long time, if we were to make an aeroplane service worth while.

Colonel L. F. R. FELL referred to the author's remarks on the type test, which it was suggested should be made stiffer. The type test had been one of the greatest troubles and for a very good reason. The cost of running a type test on an engine of about 500 h.p. was something like £20 per hour, taking all expenses in, so that nowadays with the small orders that were coming along for aircraft engines it was a large item to have to add to the overhead expenses, such as £20 an hour for 300 hours, and that was why it was not really done. At the moment, the test was considered to be absolutely as severe as anybody could possibly stand. It was now under consideration to make it a 50 hours run non-stop, beginning at definite times, but whether that would be agreed to or not, he did not know. With regard to modifications, he thoroughly agreed with the author about that. He knew the case which was referred to in the paper and it certainly was a very bad one, but in future he did not think it could possibly occur. The engine in question at the time had not passed the type test and it only had a limited approval, but since then it had done the test and now was approved. In future, an engine that had done the type test could be taken to be satisfactory, as satisfactory as it could be made, and we should not have any more cases of that sort.

The CHAIRMAN said Colonel Searle's objective was to encourage the quick transport of persons and suitable goods. This was one of the very big things with which the world was concerned. When achieved it would make, as much

as the Washington Conference, for the diminution of armaments, since it would spread a good understanding amongst peoples. Quick transport, by leading to personal contact, overtook misunderstandings and killed them rapidly. It was an economical thing for any country to encourage, because it has been proved time and again how expensive it is to kill a lie later on, and a cleverly distributed lie might mean war. That was a general principle and was among the reasons why aircraft transport and travel should be taken seriously by this country. An outlay was not necessarily expense—it might be investment—and an investment to encourage civil transport by air should be regarded as money utilised in the direction of safeguarding peace. He was much inclined to agree with Captain de Havilland, where he pointed out that the aeroplane designer had not up to the present had a chance of launching a design after thoroughly testing and trying it out. He had never been allowed to do what the motor car maker did, viz., to test out and eliminate the shortcomings of next year's design by a year of strenuous use before it was put on the market. The aeroplane had always been presented to the user in its crude, raw stage, and that had, in all probability, conduced to justify Colonel Searle's critical attitude in his paper. He was in agreement with those who deplored the advocacy of 30 per cent. increase of engine weight. To suggest the abandonment of alloy steel was mere retrogression. He personally considered that aircraft progress was bound up with the improved use of light, strong structural materials and methods—and among these were the heat-treated high tensile alloys of steel. Similarly, the basis of aero engine utility was lightness, reliableness and fuel economy. Study, research and experiment would no doubt distribute the engine's weight with greater nicety—but the mere increase of engine weight could not be regarded as desirable without specific proof that a specific excess was needed in a special part. The margin of payable load at present was very small and they could not afford to waste any of it. The engine was already one-third the weight of the loaded aeroplane and to add 30 per cent. to the engine would be to eat up 15 per cent. of the paying load or alternatively the whole of the calculated profit and civil flying would shut down. He sincerely hoped that Colonel Searle would reconsider any such recommendation. That was one point of criticism, but it was not, however, meant to be an attack on the tenour of what Colonel Searle had said and with which he agreed. He would now call on him to reply to the discussion, which had, he thought, brought out several points of interest.

Colonel SEARLE, answering Mr. Handley Page, said there were a lot of transport babies at the present moment and they had been through measles, scarlatina and other troubles; if they knew when they took on air transport that they were likely to have measles, scarlatina and whooping cough, they should have taken the ordinary precautions. Instead of that they had nearly killed the child. That was his reply on that point. He quite realised the difficulties of the manufacturer in getting the ideal machine, but it was the principles of transport that they must stick to and there were a few fundamental factors which they must bear in mind in connection therewith and he would deal with the Chairman's remarks on that later on. Mr. Handley Page had said that he should not be too definite in laying down design; he had laid down no design and did not attempt to do so; he had much too little knowledge of the business as far as design was concerned, but he had a knowledge of transport and knew what was wanted. If transport operators and the manufacturers could get together, he was perfectly certain that they would solve this problem, which he admitted was a difficult one.

Captain Gillman had said that a Lloyds' Committee had been formed in June last year. He was afraid that that committee had hidden its light under a bushel to some extent. He knew there existed a register of aeroplanes and he hoped that, if such a committee as Captain Gillman had suggested was formed, it would be on more comprehensive lines and should have more influence over the Air Ministry, *i.e.*, it should have the right to give judgment on any arguments between

the Air Ministry and owners or manufacturers; to-day any suggestion or proposition could be turned down by the Air Ministry and the owners or manufacturers were helpless. That was why he agreed with Captain Gillman that there should be some form of Court of Appeal.

With regard to grazing and the taking of land, he had economy in mind and was afraid that somebody would make some rude remarks that in these times there must be some economy and, therefore, he thought it cheaper to suggest grazing to ease the Ministry of some of the cost, even if it were at the expense of a cow or two.

On the question of taxi-ing, he felt strongly that something should be done to make a hard road or, better still, to place the sheds where the machines usually started from so as to avoid taxi-ing altogether, because he was perfectly certain that it was an expensive item.

As to his views on transport in Great Britain and Ireland, he should be very sorry to touch Ireland at the moment but, as far as Great Britain was concerned, we had first got to solve our present difficulties and really learn our business between London and Paris, which was an established route. When we could do that at a profit it did not much matter where we went, in this country or the other, but we had first got to satisfy everybody that the business could be run at a profit. If a profit could not be earned, then civil aviation was bound to die; Mr. Handley Page could not expect it to be kept on by subsidies for more than ten years anyhow.

With regard to Colonel Ogilvie and engine prices, he rather fancied the information which Colonel Ogilvie had given was wrong or he (Colonel Ogilvie) must be getting his engines in a very much cheaper market than he (Colonel Searle) could get them.

Colonel OGILVIE said that he had not been buying, but he knew that the figures he had given were the right prices.

Colonel SEARLE replied that this was not quite the moment to go into engine prices, but he would be pleased afterwards to do a little multiplication and division sum with Colonel Ogilvie in which he thought he would get a lot nearer to £6,000 than £2,000. He agreed that perhaps it was not quite a fair way to put it in speaking of price per ton, but he thought that it demonstrated that much greater thought would have to be put into the problem of reducing engine prices.

Major Green had said that it was utterly stupid to think that we were not going to improve things. Of course we were. On the question of weight, Major Green had suggested why not make them of cast iron. No such suggestion was made in the paper and it would be utterly absurd to think of it. The first thing was that we had got to make a good engine, but there were many ways of doing it. The point he wished to bring out in the paper was that, even if they had to sacrifice weight, they must have reliability first. It was no use saying that what they had got to do as designers was to make a lighter engine and a lighter aeroplane. The first essential was to keep the service reliable, and if the machines were not reliable they would all have to go out of business. When Major Green said these things were utter stupidity, he would like to ask him, taking the motor car business, what he would think of a man trying to motor from London to Glasgow with twenty pieces of indiarubber tubing between the petrol tank and the carburettor; everybody would think it very foolish, but it was these little things which designers must bear in mind and what he wished to impress was that they must have reliability even if it was at the expense of a little weight.

Colonel Fell spoke on the matter of type tests. He was perfectly aware that it was a very big drain on a manufacturer to do a type test, such as was mentioned in the paper, but again he must come back to the question of reliability which they must have even if the Government paid for the type test. He felt

sure that the test to-day was not what the engine had to do in ordinary work; why not make the test equal to what the engine had to do in ordinary practice? The job was 2 or $2\frac{1}{2}$ hours flying outward and 2 or $2\frac{1}{2}$ hours homeward and that had to be done every day for a month on end. When they could do that they had a reliable engine. That also replied to the Chairman's remarks. Hitherto, we have been getting what one might call a beautiful engine, but we had got to get a reliable engine. They must have that in any case and he was perfectly willing to sacrifice some weight in order to get it.

The CHAIRMAN, in proposing a hearty vote of thanks to the author, said that Colonel Searle was a very busy man, but he had taken serious trouble in this matter and had done very well by them in preparing such an interesting, instructive and suggestive paper, the discussion upon which had also been useful. It gave them the opportunity of seeing the point of view of the man who had got a transport business to run, and it was an opportunity which would be valued by those who were present.

Mr. DERMOT MOONEY (*communicated*): I do not think the lecturer is right in thinking that the day of the all metal aeroplane is far off, or that at best it will be a composite structure; nor is there any indication that the official view on metal construction coincides with the opinions expressed by him.

A great deal of research and experimental work has been done on metal construction, with both successful and encouraging results.

Extended flight tests of metal wings have been and are being made at home and abroad.

All this is giving information which will be very valuable for constructors.

I feel certain that if Colonel Searle knew of all the progress which has been made he would modify, if not entirely change, his opinions on the subject of metal construction.

It is not perhaps permissible or advisable on an occasion like this to go into detail, but speaking generally, very considerable and satisfactory practical progress has been made, especially with all steel construction.

The system adopted by those engaged in working on the problem in this country has resulted in the evolution of a type of steel construction which already appears to be superior to anything produced abroad.

Some complete all metal machines have been made in England, but most of the experimental construction and flight work has been concentrated on what I think is the most difficult part of the problem, the production of light, strong, efficient and durable all steel wing structure.

I will summarise the result by stating that already steel wings have been and are being made, which are as light and as strong as those constructed of wood.

Tests which have now extended over several years show that these wings are more durable, that they are less liable to destruction in case of accident, and that they are not subject to distortion by climatic or atmospheric variations, the latter an important point in machines intended for international civil aviation.

The lecturer has, I think, rightly said that the success or failure of civil aviation will depend on its cost and that in effect cost is the governing factor. Therefore anything that reduces cost will be an aid to the progress of civil aviation.

The experience of metal construction available is such that I have no hesitation in stating that the structure of an all steel machine will be more durable and require less adjustment than that of a wooden machine and consequently its mileage and appreciation costs will be lower.

As regards capital cost.

Given conditions which are already practical, that will not be greater than for wooden construction.

Moreover, the results I have indicated can be obtained by use of steel which is a present day commercial product and not a laboratory one.

Lieutenant-Colonel V. C. RICHMOND (*communicated*): I listened with great interest to Colonel Searle's practical discourse on the requirements and difficulties of air transport. I hope I shall not be considered unduly critical when I say that I was rather misled by the title of the paper, which is practically confined to remarks on the Paris-London Aeroplane Service.

Colonel Searle mentions that we must visualise as clearly as we can the essential characteristics of the problem. The most important of these seems to me to be under what circumstances can transport by aircraft provide such benefits to the public as to make them adopt this form of transport, even at a cost which is higher than that of other existing means. I cannot help feeling that the fact is too often lost sight of that the real benefit of air transport over a given route does not lie in the speed made good, nor yet in the percentage time saved, but in the actual net gain in time. When existing facilities can perform the journey in less than 12 hours, the circumstances under which it is of any value to reduce this time are very limited. By this I mean that if a business man can leave his office about the usual time of 5 p.m. and arrive at his destination before business commences next day, a good many of the ordinary interests of commerce are fully served. We can, of course, already do this between London and Paris without taking to the air at all, and I feel that very great credit is due to the companies who have already tackled the problem of air transport over this line, particularly because they have chosen a short route already served by sea and land transport developed to its maximum paying speed.

This is contrary to transport practice, and one may point out as an illustration that road transport started over routes where rail facilities were bad, and it was only after considerable experience had been obtained on these routes that it directly challenged the railways on their own main routes.

Colonel Searle distinctly stated that if the Paris-London Service could not be made a paying concern the future of civil air transport was doomed. I hold an entirely different view and consider that we must develop long distance routes where there will be a net saving in time of days, and the argument that "we must walk before we can run" does not, I think, apply in this case, because the commercial experience gained on the cross-channel service is not likely to be of much assistance in running really long distance routes, and this route is one which is least calculated to be a paying concern for the reasons stated above.

When we come to the consideration of such routes we see how many of the points raised in Colonel Searle's paper show the difficulty of attempting transport on these routes with planes. There is the absence of the usual comforts and conveniences of travel, and it is doubtful if the ordinary individual could stand the journey to India by plane without long and frequent stops. There is further the need of lighthouses fairly close together, as Colonel Searle has pointed out, and the very small flying hours per machine per year, and the consequent low percentage of capital value in use at any time will become still more serious on these long routes. There is further the necessity for frequent aerodromes and emergency landing grounds, also the narrow margin of available lift and the fact that the lift of the plane depends on its engine, which Colonel Searle points out is in its present state unreliable. Most of these disadvantages would be got over by the use of airships, and it is quite a mistaken impression to suppose that they

usurp in any way the functions of the plane. I firmly believe that a real commercial success (on a fair scale) will not be made with air transport until both classes of craft are used together. One of the functions of the aeroplane will be to act in the future as the taxi to the airship, *i.e.*, if one chief landing centre for airships is provided in each country or colony, the aeroplane will avoid any loss of time by taking the passenger from that landing centre to whatever part of the colony he wishes to reach.

General Sir W. S. BRANCKER (*communicated*): I regret that my absence in Paris for the Air Congress prevented my attendance at Colonel Searle's lecture on "Aerial Transport," but I venture to ask for the publication of the following remarks:—First, out of loyalty to my old organisation, Aircraft Transport and Travel, as well as for the sake of aerial transport, I must criticise some of his statements.

I agree with every word he says, but I don't agree with the way he says it. Every precept and principle which he lays down was realised and accepted before he had even appeared on the stage of aerial transport. He criticises the employment of a large number of unsuitable machines; but if they had not been used nothing could have been done at all; and it was the constant effort to make improvements which led to a multiplicity of types and consequent large numbers. Actually the first really economical machine in the world was produced and was flying for the company before Colonel Searle arrived, and it was only *after* his arrival that a programme involving the construction of eight similar standard machines was abandoned, and operations continued with the old types, which everyone knew ought to have been scrapped. He says that someone—who must be either General Festing or myself—stated that an aeroplane could only fly 250 hours in the year. This is not so; I always said that the number of hours that a machine could fly depended entirely on the efficiency of the administration and on the efficacy of the weather-combating organisation, but that, until we had obtained real experience as to what could be counted on, I would make my estimates of costs and plans on the basis that a machine *could* fly 250 hours, whatever happened, and that, therefore, we should always be on the right side in our calculations. He talks as if no calculations had been made; actually, the whole of the costs had been most carefully worked out and the estimates have been pretty well borne out by subsequent operations.

Colonel Searle does not touch on two important points on which I should have liked to hear his views; the numbers of hours pilots should be called on to fly; and the type of machine which is required for the real reliability of service for which he is striving. I feel strongly that there is a tendency in some directions to over-work pilots for the sake of saving money; this is utterly false economy and will only lead to unreliability and unnecessary danger. In present conditions I feel that no pilot should be called upon to fly more than five hours in one day, or sixty hours on the average, a month, in a regular service where flying by night and in all weathers is imperative. In addition, he must be given leave at the rate of about ten days every three months. Regarding the type of machine employed, I am convinced that stability is a factor of utmost importance, and I feel that we are rather losing sight of this fact and concentrating almost exclusively on useful load and durability.

Finally, Colonel Searle's lecture makes me a little apprehensive lest a business and transport expert, without real knowledge of aviation, may not do aerial transport more harm than the common-sense man who understands aviation but has no business training.

Mr. G. HOLT THOMAS (*communicated*): I regret that the date of Colonel Searle's lecture clashing with the International Congress in Paris, I was unable to be present. I am, however, writing a short comment on his lecture as, perhaps unintentionally, he reflects somewhat on my managers at the start of the London-

Paris Air Express. As a matter of fact I agree generally with Colonel Searle in so far as running an aeroplane service for profit is concerned, but he forgets that the first thing to do was to find out, with the means at our disposal, whether an aeroplane service were possible. Nobody knew at the time the air express was started whether it was possible to fly between London and Paris daily to scheduled time, with sufficient efficiency to be commercial. I am popularly supposed to have as much experience of flying as perhaps anyone in the world, but I can frankly say, with the climate we have between these two capitals, that I could not answer this question without a test. Colonel Searle says, "It is perhaps easy to be wise after the event"; but so far as I am concerned, I was no wiser, and, looking back, I can say quite frankly that I would do the same thing again. I should never have attempted to design rolling stock for any transport until I knew whether such a service were possible, and to find this out I took the war machines existing and the finest pilots I could find. The efficiency of the service was an eye-opener to the world, and was due to the loyalty of the pilots. They were determined to get through whenever possible, and if I were to select men again to do the same thing, I should, generally speaking, select the same.

After it was proved that a service between London and Paris was possible, I do not think that any management could have been quicker to appreciate it than my own. The service was started on the 25th August, 1919, and, as far as my memory carries me, I should think that by October 25th Captain de Havilland was on to a really commercial design, suitable for the purpose, resulting in the D.H.18, one of which was delivered when Colonel Searle took charge, and I regret to say that his directors were responsible for stopping the delivery of the rest of the batch, ready for the spring of 1920. At this time also the commercialising of aerial transport was a perfectly natural sequence. On looking back, even to-day, with the much greater knowledge at our disposition, I can only see that the three definite steps taken were absolutely necessary, viz., firstly, the trial of a service with the machines available and the best pilots obtainable; secondly, when proved possible, the design of suitable rolling stock; and thirdly, bringing the service down to a purely commercial problem; but I think my management would have been very much at fault if they had in any way reversed these processes; and the fact that Colonel Searle had not the proper machines for the service to deal with shortly after he took charge was, as I have said above, not the fault of the pioneers of this service, but the fault of his own directors who stopped the delivery. This was the more regrettable as the machines, even if the service had been stopped as it was proposed to be stopped, would have been saleable, with a great many replicas, to many other nations, and the founders of the first British service would also have had the very remunerative task of running other services in many parts of the world.

I am so much in agreement with Colonel Searle's general statements that I hardly like to comment on his lecture, but at the same time I cannot let his observations on the foundation of the service pass without comment, as the steps necessary to its establishment were so obvious and, indeed, the service could not have been arrived at in any other way.

REPLY TO WRITTEN CRITICISMS.

Mr. Mooney.—Mr. Mooney is apparently an enthusiast in the all-metal aeroplane and his comments really amount to a statement that the all-metal aeroplane is nearer a commercial proposition than I understand. The research and experimental work in this direction, which he states has been done, if from lack of publicity, one is to interpret secrecy, then the results must have been either very successful or the reverse. In any case, Mr. Mooney's statements are all abstract and he gives no facts. As we have no information yet available as to

the life of the ordinary wood and fabric aeroplane, it is difficult to make comparison with the all-metal machine other than that, as we all think, metal will withstand the weather perhaps better than wood. As far as capital cost is concerned, Mr. Mooney qualifies his remark by conditions, the practicability of which is only based on Mr. Mooney's abstract statement.

Colonel Richmond.—Colonel Richmond is quite correct in saying that my paper is practically confined to remarks on the London-Paris aeroplane service. Where else has commercial aviation been attempted on anything like such a scale? This route would naturally be referred to as a basis because it is the only one on which any serious development is taking place and on which the eyes of the air transport world, so to speak, as well as the public, are fixed. Colonel Richmond dismisses in a few words the discomforts of a night journey to Paris and, in fact, he converts the most uncomfortable civilised night journey which I know into almost a pleasure trip for the business man. Furthermore, I abide by my statement that if the London-Paris Air Service cannot be made a paying concern the future of civil air transport is doomed, but in making this statement, I am referring naturally to aeroplanes alone. The London-Paris route has all the best ground equipment and organisation lavished upon it; it has a constant heavy passenger and goods traffic available and it affords a unique example of superiority of air travel by reason of the interposition of the English Channel. It is, therefore, of the utmost importance to air transport that the London-Paris service be made a commercial success. As far as airships are concerned, and in which Colonel Richmond appears particularly interested, I am convinced that the airship, as a transport vehicle, is capable of paying its way, but there seem to be very many technical difficulties in the way at present. The two in particular which remain outstanding in my mind are, firstly, that of the deteriorating effect of sea air upon a duralumin structure and the difficulty of keeping a preventative coating upon such a structure which is constantly working at almost every joint. Secondly, there seems to be a great difficulty in preventing gas leakage and in handling the gas in varying altitudes. I am entirely in agreement with Colonel Richmond on the importance of the airship for developing Dominion and Colonial communications and, to my mind, it would be a great pity if we scrapped some 45 millions which have been spent on airships for the sake of spending another quarter of a million to determine definitely their value.

General Brancker.—I can only repeat what I said in my paper that I was told by a high authority on flying that an aeroplane could only fly 250 hours a year, and I will now add that it was generally taken for granted in the air world that 250 hours a year was about as much as a machine could do. I am entirely in agreement with General Brancker on the number of hours which pilots can be called upon to fly, although for summer work I think that 60 hours a month is on the small side if it is not going to be reached in the winter; air traffic is somewhat similar to omnibus traffic in that it increases considerably in the fine weather, so that I think the summer average for pilots will probably be as much as 80 hours per month and in the winter as low as 40. I am also in agreement with General Brancker's view that pilots should have ten days or a fortnight's leave at definite periods.

General Brancker is quite correct in stating that I was responsible for cancelling the construction of the eight D.H.18's to which he refers. This cancellation cannot be interpreted as a disapproval of the mere ordering of those machines, but as General Brancker has entered into details so far it is necessary to complete and to say that at the time these machines were being built there was already something like £60,000 worth of aircraft on the books of the Air Transport and Travel Co. The financial responsibility of bringing eight more machines, or about another £50,000 on to the books of the company, as a debt to the parent company, will be obvious to a business man when the following facts are considered.

The original £60,000 of aircraft were capable of carrying something like 120 passengers a day at one trip per day each machine; the new eight machines provided a further capacity for 144 passengers a day on the same basis; at this time the number of passengers being carried on aircraft generally amounted to about 30 a day, and as there were vacant seats it is to be assumed that that is the number available. General Brancker suggests scrapping the £60,000 worth of aircraft, but the action of scrapping the material and the cleansing of the balance sheet after such an operation are two very different things which General Brancker does not appear to have considered.

With reference to General Brancker's apprehension in the last paragraph of his letter, my own feeling is that a commercial engineer and transport expert should gain the equivalent knowledge of what is termed "aviation" to the air expert in very much less time than the average air enthusiasts could learn the principles of business.

Mr. Holt Thomas.—Mr. Holt Thomas's letter of comment is so logically put together that in reading it one is likely to be carried out of sight of the main facts at issue. He also, however, refers to the cancellation of the D.H.18 order to which I have already replied to General Brancker.

With reference to the main point which figures throughout Mr. Holt Thomas's letter, viz., that of the establishment as fact as to whether an aeroplane service was possible, surely this could have been determined with two D.H.4's or 16's instead of a collection of about 25 machines, most of which varied one from the other, and a young Air Ministry to run them.



PROCEEDINGS.

FOURTH MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts on Thursday, December 1st, the Chairman, Lieut.-Colonel O'Gorman, in the chair.

The CHAIRMAN, in opening the meeting, said it would be a pleasure to hear Major Scott, because he had given such exceptional proof of his faith in his subject—airships. He was one of the few now alive who had flown over the Atlantic, and as they knew, Major Scott was in charge of the airship which crossed to America. Major Scott had asked him to mention that although the printed title of the paper was "The Present State of Airship Development," that was an error. As printed, the title rather suggested a political significance, in view of the fact that no one quite knew to-day how England stood with regard to airships at the present time. The paper dealt with the technical position, and the title should really be "The Present Technical Position of Airships."

THE PRESENT STATE OF AIRSHIP DEVELOPMENT.

Introduction.

At the time when the question of the development of civil aviation is so much in the public mind, I am most grateful to the Royal Aeronautical Society for giving me this opportunity of summarising the technical position of the airship to-day.

It seems to me that if air transport is to take its place with other existing forms of transport the long distance routes of the world must be established, and my object in summarising the present technical position of the airship is to enable you to form an opinion as to whether the modern airship is capable of taking its place in establishing these routes.

I have confined my remarks to the rigid as it is the large airship which is the most suitable for this long distance work.

As this long distance work has a distinct bearing, in my opinion, on the value of the airship for naval purposes, I have made a brief reference to this aspect of the subject.

In considering the present state of technical development it is possible to deal with each of the individual parts separately, and this I propose to do under the following headings:—

- (1) Hull.
- (2) Fabric.
- (3) Engines.
- (4) Safety.
- (5) Handling on the ground.
- (6) Handling in the air.
- (7) Navigation and wireless.

Hull.

The hull of an airship is constructed of a number of rings or transverse frames, these rings being composed of straight duralumin girders forming the circumference, and prevented from radial distortion by wires connecting the ends of each straight girder to the centre. These wires are known as radial wires.

These transverse frames are spaced axially along the ship and connected by straight girders known as the longitudinal girders, this whole framework being stiffened by diagonal wires between adjacent longitudinals.

At the bow and stern these transverse frames are reduced in diameter, thus giving the required shape.

In early rigid airships a strong external triangular keel was attached to the hull, but built separately from it.

This keel carried all the loads, the petrol and water ballast being slung inside the keel, and all cars or gondolas underneath this keel and transmitting the propeller thrust to the keel, and in the very early airships the rudders and elevators were also built on to this keel.

The lift of the gas was taken by nets, which transmitted it to the main transverse frames. From each joint in this main transverse frame, lift wires were carried down to the keel.

Owing to the slow speed of these early ships, and their small size and therefore concentrated loads, the dynamic forces on the ship were light, whilst the static forces were heavy.

This external keel was constructed strong enough to take all these loads, the hull being little more than a framework to take the gasbags, and transmit their lift down to the keel, the keel dealing with all bending moments and shear forces.

This principle of an external and separate keel was followed out in the naval airship No. 1, and in R.9 and the R.23 class.

With increase in size and consequent increase in speed a better streamline form became necessary, the streamlined form being first introduced by the Schutte Lanz Co., in 1909, although not copied by the Zeppelin Company until many years later.

The ratio length to diameter for this first streamlined ship was 7.1 to 1 as compared with 9 to 1 for the contemporary Zeppelins.

The reduction in fineness ratio reached its limit in the German commercial airship Bodensee, with a ratio of 6.5 to 1; this ship had a speed of 81.2 m.p.h.

The increase in speed resulted in an increase in dynamic forces; it therefore became necessary to increase the strength of the hull structure, and deeper girders were introduced.

The hull was now capable of taking some of the shear and bending loads, and owing to the difficulty of estimating proportions of load taken by keel and by hull structure, when separate, the keel was built inside the hull and as part of the hull, the keel, however, still acting as the load carrier between the main transverse frames.

This introduction of an internal keel reduced the over-all height of the airship and allowed a larger diameter ship to be built in the existing sheds.

With the introduction of the larger diameter it was found that the stresses in the radial wires became excessive from the end pressure of the gasbags when the ship was pitched at a steep angle, or the gasbags were not all at the same degree of fullness.

To release this tension in radial wires, an axial wire was introduced. This wire runs longitudinally through the centre of the ship, passing through the gasbags, and connected to the centre pad where the radial wires meet.

Shear wires were also introduced; they lead from the top of one main transverse frame through the gasbag to the keel at the foot of the adjacent frame.

They were only fitted in sections where the loading was heavy and therefore shear forces big.

The increased number of engines now carried by airships necessitated the intro-

duction of wing power cars in order to allow a clear run for propeller slipstream and prevent interference.

In the very early ships, fins, rudders and elevators of the box type were employed, but these were superseded in 1912 by the simple fin, but with increased speed the head resistance of this type of fin became excessive owing to the large amount of external wiring required to support it, and in 1918 streamlined or cantilever fins were introduced.

This brings the British airship up to the R.36 class, which can be taken as a thoroughly proved design, embodying no experimental features.

Her dimensions are:—

Length	672.2 feet.
Diameter	78.75 feet.
Capacity	2,101,000 cubic feet.
Gross lift	63.8 tons.
Useful lift	23.5 tons.
Horse power	1,570.
Full speed	56 knots.
Cruising speed	45 knots.

Germany has proved one step ahead of this country by the introduction of 15-metre gasbags, *i.e.*, main transverse frames are spaced 15 metres apart instead of 10 metres as in British and previous German airships.

These 15-metre gasbags were employed in all ships of the L.60 class and in the L.71 and L.72 and proved satisfactory.

It was found after trials that the greater distance apart of the main transverse frames caused vibration of the keel or corridor, and stirrup wires were introduced. These wires lead from the top of the main transverse frames through the gasbags on to the corridor, midway between main transverse frames, supporting the corridor at this point; they also, to a certain degree, take the place of shear wires.

The next step taken by this country was the construction of R.38.

R.38 embodied the 15-metre gasbags, but omitted stirrup wires. Other new features introduced were:—

Increased diameter from 80ft. to 85.6ft.

Modified form of corridor, the old triangular form being superseded by a four-sided section.

New method of gasbag wiring, the nets and diamond form of gasbag wiring being replaced by circumferential wires, running parallel about 9in. apart right round the ship. The lift of the gas is taken by these wires and is transmitted from them to the main transverse frames by catenary wire, a new feature of this design.

Larger petrol tanks were introduced in order to concentrate the loads at the main frames.

Previous tanks were of 80 gallons capacity and the new R.38 tanks were of 160 gallons capacity.

A modified form of balanced rudder and elevator were also introduced.

As stated in the report of the Court of Inquiry, R.38 was wrecked due to structural failure in the air.

A careful investigation into the causes of this failure is at present being undertaken by the Accidents Investigation Sub-Committee of the Aeronautical Research Committee. I am not at liberty to make any statement at present.

Some of the features introduced into R.38 are no doubt sound and it must

be realised that R.38 was designed for a very special performance, and the trials indicated that this performance would have been realised.

Summarising, there is in existence to-day an airship of the R.36 type, proved and tried out, with a performance as stated earlier.

Also it would be possible to build an airship of 2,500,000 cubic ft. capacity without embodying any new features that have not already been tried out and proved in this country or in Germany.

Fabric.

The hydrogen to which the buoyancy of the airship is due is contained in bags which must be as light, gastight and flexible as possible. The material which was first employed by the Germans was cotton proofed with rubber. The Germans were not long in deciding that this was unsatisfactory; even with such a relatively high weight of rubber as 150 grammes./sq. metre, a very good permeability could not be obtained. (At the best about 6 to 7 litres/sq. metre per 24 hours.) At this time the subject had not been sufficiently studied for a really durable type of coating to have been produced. The Germans lost one or two ships by fire, notably the "Schawben," and they attributed the fire to static electrical discharge. This discharge they imagined arose from the friction of the rubber on the hull of the ship. They then turned their attention to the use of goldbeater's skin. This substance, which forms part of the intestines of the ox, is remarkably light and strong. In addition, it has a lower permeability for its weight than almost any other known substance. One layer of the skin is far too fragile to be used by itself, and in the early days bags were made of as many as seven to ten layers. This was very costly and involved an enormous amount of labour, as each skin is not much more than 1 ft. square. A definite advance was then made by employing goldbeater's skin in conjunction with cotton, the cotton giving the necessary strength and the goldbeater's skin the necessary gastightness. Under these circumstances, two layers of goldbeater's skins are sufficient, which with the weight of the adhesive employed need not be more than 60 grammes./sq. metre. The permeability of this composite fabric rarely exceeds more than 1 litre/sq. metre/24 hours, if carefully made. This you will see constituted a very distinct advance over the original rubber proofing referred to above. The medium employed to attach the skins to the fabric is a matter of some considerable importance. The Germans have employed a gelatine glue, whilst a rubber solution has been used in this country. Also the actual method of laying the skins was different in the German case to that employed here. In the course of extensive experiments which have been carried out in Egypt this year, it has transpired that the thin film of rubber employed for adhesion suffers badly under tropical conditions, and is in all respects an unsuitable substance to employ on airships which will have to do much flying under tropical or semi-tropical conditions. Samples stuck with gelatine glue have not suffered in this way, and hence there is no doubt that we can make gasbags in this country on the German principle which will be durable under the conditions referred to above. The glue adhesive used is fortunately a fair conductor of electricity, and therefore the original German objection to employing an insulating material, such as rubber, is done away with. So that to-day it is possible to build gasbags capable of withstanding all weather conditions met with in this country, and giving a life of at least two years, and from the result of sample tests we can say these bags will also be capable of withstanding tropical conditions. The objections to the use of goldbeater's skin are, of course, the enormous number of skins required (over 300,000 in the case of a ship such as R.36), and the immense amount of labour in laying these skins, both of which causes make the gasbags very expensive. A good deal of work has been done on synthetic substitutes for goldbeater's skins, which is very promising.

Engines.

The requirements for an airship engine are essentially different from those of an aeroplane engine, and are not met by the latter, yet no British airship engine has yet been developed, the only engine designed to meet airship requirements being the German Maybach.

In the past airships in this country have been obliged to use engines designed for aeroplanes, and even of such engines it has not been possible to select the most suitable.

The average requirement of an aeroplane engine is a few minutes at full power followed by some five to six hours at about three-quarters power.

The airship requirements are considerably more exacting; for commercial airships the average flight will be about 50 hours, and the engine will be required to develop three-quarters full power with occasional stops for the full period, or to develop full power for three-quarters of this period.

The aeroplane engines employed in the past could not be relied upon to stand up to either of these conditions, which is reasonable in view of the very different conditions for which they were designed.

The modern airship starts its journey with about 20lbs. of fuel for every rated horse-power of the engines, while the corresponding figure for aeroplanes does not often exceed five.

This indicates the relative importance of fuel economy and engine weight in the two cases, thus a 10 per cent. increase in fuel economy under working conditions is equivalent to about 2lbs. weight per h.p. in the engine.

An engine designed for airship work may therefore have a higher weight per h.p. provided there is a corresponding decrease in consumption, and such an engine running at lower revolutions would be more reliable and have a longer life.

Hydrogen as Fuel.

The idea of burning hydrogen in the engine as a means of economising fuel and thus increasing the performance of the airship has been under consideration for some time, but until recently no satisfactory method of burning hydrogen alone or hydrogen and petrol mixed, had been devised; recent experiments, however, have indicated a method of using the two fuels mixed, and this should very greatly increase the performances of the airship in the future.

The use of kerosene or crude oil to replace petrol in both aeroplanes and airships would substantially decrease the danger of fire, as although the danger of fire in airships is small, what danger there is, is almost entirely due to the presence of petrol. The development of the use of kerosene or crude oil is obviously important for commercial airships, and can be confidently predicted once this demand is realised.

Propellers.

In the early airships the propellers of an airship were carried on brackets attached to the hull and driven by gearing and shafting from the engine car.

This method was superseded in 1916, and all propellers placed at the after end of their respective power units and driven through reduction gear.

A later development in German airships and now copied in British airships was to put a direct drive between the engine and the propeller, a very small compact power car being employed.

The efficiency of the gear-driven propeller is higher than that of the direct driven propeller, but this is to a certain extent nullified by the large power car required and the longer struts and suspensions necessary owing to the larger diameter propeller, thus increasing the head resistance of the power unit.

The increased reliability of direct driven propellers is a big factor in their favour.

Summarising, there is no airship engine in existence in England to-day but the requirements are such that there should be no difficulty in constructing a suitable engine.

Taking the German Maybach as an example, all present requirements are met.

Future development in airship engines should work toward the use of heavy oil and reduction in consumption. The value of reduced consumption to the airship is not generally realised.

Safety.

I think it is not generally realised that on the occasions when modern airships of proved type have been wrecked it has invariably been due to accidents happening whilst handling on the ground, this of course excluding losses due to enemy action.

The question of the safety or danger of a modern airship may be considered under two headings: (1) dangers due to fire, and (2) dangers due to weather conditions.

The dangers due to fire may be again sub-divided into those due to petrol fuel and those due to hydrogen.

Firstly, as regards petrol, contrary to popular opinion the danger of this source is considerably more serious than that due to hydrogen. Although this danger is certainly no more serious than that due to the same cause in an aeroplane, it is obvious that every effort should be made to eliminate it. This should be possible in the near future by the use of high-flash-point fuels already referred to, mechanical refinements of the fuel installation, and the abolition of any contributory causes of fire such as sparks from electric leads.

As regards hydrogen, in all cases of fire in rigid airships, the ignition of the hydrogen has been a secondary cause. These cases are few except for enemy action. In such operations where the present type of airship can be reached by heavier-than-air craft with incendiary ammunition, there is no doubt it is very vulnerable and its naval use accordingly limited. It must be remembered, however, that owing to its superior range there are many areas of operation where the heavier-than-air craft could not engage.

The question of the protection of the airship against incendiary attack has not been fully worked out, although experiments with the use of helium, and in the use of an outer envelope of non-inflammable gas, have given very promising results.

The successful development along these lines would entirely remove the disadvantages of the present airship's vulnerability when operating where heavier-than-air craft can attack.

Weather Conditions.—I have already pointed out that a hull of $2\frac{1}{2}$ million cubic feet could be built to-day with the same factor of safety as R33 and R34, which ships have safely weathered the worst conditions in the air. The dangers that might be met in the air are:—

(a) *Electrical Disturbances.*—The chief danger in an electrical disturbance is not as is generally thought due to lightning, but to the very violent air currents that might bring excessive strains on the hull structure. It is, however, even with the present meteorological organisation, which is not specially arranged to meet airship requirements, and with present air knowledge, comparatively easy to avoid thunderstorms. I can definitely say that thunderstorms in this country do not constitute a danger to airships, neither will they constitute a danger in the

tropics, for the reason mentioned above, as with the development of airship routes the meteorological organisation will be extended to meet our comparatively simple requirements.

(b) *Snow*.—The danger from snow is the possibility of the airship becoming so heavily coated that she will be driven to the ground. Experience in the air and from maintaining a ship at the mooring mast, points to the fact that little danger exists from *dry* snow, as this snow blows off and does not collect on the ship. *Damp* snow and sleet are the chief dangers. When flying through snow and sleet, however, at the first sign of snow collecting the ship can rise into the dry snow, 1,000ft., in most cases, being sufficient.

Handling of Airships on the Ground.

The handling of the airship on the ground has until recently been the limiting factor in the usefulness of the airship.

Thus an airship operating from a shed was handicapped by the fact that except in moderate winds the airship could not leave the shed, and an airship arriving back at a base was obliged to wait for a suitable opportunity to enter the shed. This often resulted in an airship being recalled at the first sign of bad weather, as although there was no difficulty of the airship flying through the bad weather, it was essential to house the ship before the wind became too strong.

Recent experiments with a mooring mast have demonstrated the fact that an airship can moor out in bad weather, and also that an airship can land or leave in weather in which it would be absolutely impossible to handle her out and into a shed.

To summarise the results of these experiments.

It was proved that an airship could remain at a mooring mast, comfortably, in winds up to 60 m.p.h., riding through hail and snow squalls.

It was demonstrated that a ship could, with ease, leave a mast in a 40 m.p.h. wind.

It was demonstrated that a ship could land at a mast in winds up to 32 m.p.h.

It was shown that necessary running repairs could be undertaken on a ship at the mast with safety.

It was shown that the hull deterioration, at a mast, is not heavy, the outer cover and gasbags were not so satisfactory; but as a result of sample tests carried out in Egypt, I think we can confidently say that the cure for this trouble is well in sight.

I will now discuss the advantages to be obtained from the use of a mooring mast.

From the service point of view there are two very big advantages.

During the war it was often found that when a large airship was particularly required, it was unable to leave its shed owing to the difficulty of handling in a wind. With a mooring mast at least one large ship would be maintained at the mast, and could slip in any weather at very short notice, thus taking the place of the fast light cruiser. Also in the event of naval or military operations in any part of the world where no shed base was available, mooring masts could be quickly and cheaply erected, thus allowing airships to operate.

The commercial value of the mooring mast is even greater. An airship working from a mast can be relied upon to leave regularly at scheduled time, and provided the weather is not too bad to fly, which is a very rare occurrence, it can land without danger, thus making a regular airship service possible.

Another point of equal importance is the great reduction in personnel. Instead of requiring a large landing party of three hundred to four hundred men to handle a ship whenever she lands, a mast crew of only 10 men is all that is required, and only in the event of docking a ship at one of the main shed bases is a large

party required, and then not so large as hitherto, as the airship would only be housed under good weather conditions.

In considering an airship route, another point of great importance is the reduced number of sheds necessary, as instead of having sheds at each landing ground, they would only be necessary at the terminal or special junction stations. This will mean a very great reduction in capital expenditure on any airship route.

Handling the Airships in the Air.

I will now discuss a few points relating to general airship flying.

In most modern airships the engine cars are arranged so as to have **one** power car on the centre line right aft. This practice has, however, in **some** ships been modified, notably in R80 and the R38, in these ships a pair of power units being placed aft.

There is little doubt that the earlier practice is better, giving better control at low speeds owing to the slip stream of the propeller acting on the rudder, in the R33 class it being possible to swing the ship about on her rudder, without losing or gaining ground, by running ahead on the after car and astern on the two wing units.

A single car aft is also of great value when handling on the ground, as it forms a foot on which the airship can rest, and a handrail to which the landing party can hold.

The effect of size on performance is of fundamental importance and has a marked bearing on all future development.

The lift of an airship varies as its (linear dimensions)³, being proportional to the total volume of the gas contained in the gasbags.

This should be clearly distinguished from the lift of an aeroplane, which is proportional to the area of the wing surface and therefore varies as the (linear dimensions)² while with airships the lift varies as the (linear dimensions)³.

The head resistance, and consequently the B.H.P. necessary to drive the airship through the air, is proportional to the (linear dimensions)², consequently with increase in size the airship can increase its speed, or if the speed remains constant the ratio $\frac{\text{disposable lift}}{\text{gross lift}}$ increases, and the ship's range or percentage weight-carrying capacity increases as the linear dimensions $3/2$.

Also allowing a constant percentage of the gross lift for fuel, the range varies in the same ratio, that is, increases with size of ship.

A very important factor to be dealt with by the pilot in flight is the superheating of the gas, either by the effect of sun radiation or sudden alteration of air temperature. The latter is generally met with on alteration of height.

The effect of this superheat is to alter the lift of the airship, and this makes her suddenly light or heavy while flying.

The airship then has to be flown at an angle to her flight track in order to produce a balancing dynamic force.

In cases where this superheating is big the loss in speed due to the angle at which the ship is flying can be considerable. It is, therefore, necessary to reduce this degree of superheating in an airship. It is for this reason the outer covers of airships are doped with aluminium, to reflect the sun's rays.

In earlier ships, and even in the case of the original cover fitted to R34, the covers were poor and afforded little protection. Recent covers, however, doped with Farnborough dope, have shown a very great improvement, and will probably be fairly satisfactory even in tropical climates.

Another method of reducing superheating is by ventilating the air space between the gasbags and the outer cover. This is done to a small extent in all airships by the gas cowls, but it is a point requiring further consideration, and one that should present few difficulties.

Navigation.

Navigating instruments employed in airships are similar to instruments used by sea craft, with the addition of the R.A.E. sextant.

This instrument is now sufficiently well known not to require a detail description; it fulfils all airship requirements, and under good conditions gives a position line with an error of between 5 and 10 miles, which is accurate enough for airship purposes.

Compasses are of standard type and can be easily corrected to within reasonable limits.

The general degree of accuracy that can be obtained in airship navigation is such that under most conditions the true position can be estimated to within 30 miles.

Wireless.

The wireless for airships is now in a position to meet all modern requirements, a sufficient range being obtained to ensure an airship being at any time in communication with a wireless base even in mid-Atlantic.

Conclusion.

In conclusion, I would like to summarise the technical position of the airship to-day from the details I have already given.

An airship of 2,500,000 cubic feet (75 tons) can be built without introducing any experimental and untried features. The hull would last, in continuous service, for at least five years, and would have a useful lift for freight of 12 tons (passengers 5 tons, mail, etc., 7 tons) for non-stop journeys of 2,400 miles, *i.e.*, England to Egypt. A journey of this distance (England-Egypt—2,400 miles) could be completed in 48 hours or at a speed made good of 50 m.p.h.

The ship would be of a rugged construction, built for long life and low maintenance cost, and with a factor of safety at least equal to the R.33 and R.34, which ships, as you know, have shown themselves capable of standing up to the worst weather conditions, both in flight and at the mooring mast.

The ship could be operated to meet commercial requirements, that is to say, arrivals to and departures from a mooring mast could be made to scheduled times and regularity on passage equal to that of steamships would be possible.

In regard to future developments, those actually in sight not only considerably improve the performance I have taken above, but also materially reduce the present cost of manufacture and operation.

Finally, I would like to emphasise three further points which appear to me most important:—

- (1) An investigation into the present commercial requirements on Imperial routes indicates that some 5 or 6 tons of mail and freight and 30-40 passengers would be available weekly.
- (2) The performance of the commercial airship which could be built to-day, and which I have given, would meet these requirements.
- (3) The urgent need for speeding up Imperial communications is acknowledged by everyone throughout the Empire and an examination of the possible means by which this demand could be adequately met, with due regard to cost, points in my opinion to the use of the airship.

As a point of interest, I would like to mention that from recent publications in Germany, it is quite clear that a considerably more optimistic view is taken in that country both as regards the present technical position of the airship and its future possibilities than that which I have given in this paper.

DISCUSSION.

The CHAIRMAN, in declaring the paper open for discussion, expressed the hope that even those members of the Society whose interests were mainly centred in aeroplane construction would not refrain from entering into the discussion through any false modesty as to their lack of knowledge of airship matters. Aeronautics was a very big subject, and he hoped there would be some representative remarks from aeroplane makers in the discussion. He called upon Mr. Burgess, of the United States Air Service, who, he said, was thoroughly well versed in airship design, to open the discussion. He added that he only regretted that Mr. Burgess was quite unwarned that he was to be called upon.

Mr. BURGESS said that in America they had been trying to develop the rigid airship. The first one was based mainly on the German L49, which was brought down about four years ago, and they had proceeded on the assumption that they should wring German experience dry before proceeding to anything new. There was, however, one point they should consider in going ahead with airship development, as the author had suggested, and that was that the Germans were designing for high altitude, whereas in commercial development, and probably even in naval development in the future, we should want long distance rather than high altitude, and although load and altitude were in a sense convertible terms, the strength required, and the reliability of the engines, and even the type of engines, were really quite different. Therefore we must keep two points in mind—firstly, to go by experience. We must not forget experience, because any *a priori* attempts in airship design would most certainly involve us in serious trouble. Secondly, it was necessary to get all the theory we could, because we must advance, and simply to go step by step in peace time would be so slow that there would be little chance of making reasonable progress in the next ten years. Therefore we must get all the experience and all the science we could together. He was afraid that possibly in the past there had been a certain antagonism between the theoretical man and the practical man, which had prevented us from making all the progress we ought to have done, and it was to be hoped now that having learned our lesson, the theoretical man and the practical man would combine forces. Another thing was that airships were now in a very precarious state, and that made it all the more necessary for us to pull together. If possible, we should get our late enemies to help us in the development of long-distance airships; certainly Americans and Englishmen must all pull together.

Wing-Commander CAVE-BROWNE-CAVE congratulated the Society on the résumé which Major Scott had given on the present state of airship technical matters. He wished to assure them that the picture which Major Scott had drawn was a very moderate one. It was completely free from speculation, and every statement he made could be very fully substantiated. To illustrate how moderate Major Scott had been, he mentioned the reference that had been made in the paper to R.38. It was merely there stated that the ship broke in the air. The point the author had tried to make in that part of the paper was that the failure of the ship must not be taken as an indication of what might happen in the future. To strengthen his point, Major Scott might perfectly well have quoted the finding of the Service Court of Inquiry which had been published, because it explained what the ship was doing at the time of the failure, and threw light on a good many pertinent matters. As, however, that case was still being investigated by the Advisory Committee, Major Scott cautiously refrained from bringing it forward. Most of them had seen that report, and knew that Major Scott was very moderate in the manner in which he dealt with that point.

The actual construction of airships was necessarily very restricted by shortage of money. The design of R.38 was really a 1918 design, and much had been learnt since. It had been possible to go ahead with a great many research

problems. Reference had been made to synthetic proofing as a substitute for goldbeaters' skin, to the use of hydrogen as an auxiliary fuel, the use of heavy oil, and many other similar questions, all of which had been investigated from the research point of view, but it had not been possible to embody them in any actual airship, because the money had not been available to build ships. However, as soon as construction started again, we ought to be able to embody in any new ship a great many features which had been tried out in experiment, and which he believed could be definitely embodied without any degree of uncertainty. Probably the greatest advance which had been made was the use of the mooring mast. How great that advance was he himself still found it extremely difficult to realise. It involved the change from having to use 300 or 400 men to work the airship out of the shed, and then being able to carry out that operation only under very fair weather conditions to a state in which it was possible to land in a 40-miles-an-hour wind, to get away in an equal wind speed, or to ride out a 60-miles-an-hour wind. That change was important enough, but one must also realise that the new system required only 10 men instead of several hundreds. Commercial success in the use of airships depended on the certainty of being able to start them in any weather, and the mooring mast had unquestionably settled that problem. He had not the least doubt that when it became possible again to tackle other problems which were equally important in connection with airship practice, exactly the same degree of success would be achieved.

Mr. WYN EVANS (Royal Corps of Naval Constructors) said that "The Present State of Airship Development" was rather a peculiar term, but Major Scott had indicated that he wished to have that corrected as the title of his paper. One would rather have wished that Major Scott had taken the main points and weighed contemporary evidence with his own vast knowledge and had given some idea of what his ideal ship should be, one, of course, that could be turned out to-day. If he might be allowed to do so, he would like to make a few remarks based on our own and German experience. To commence a practical commercial air service over a usefully long distance he agreed with Major Scott that a $2\frac{1}{2}$ million cubic feet ship would be required, and he suggested that its form should be something of the Nordstern or the new Bodensee, i.e., the form with the extra gasbag, but with slightly larger stabilising surfaces, both horizontal and vertical. This he had gathered from German evidence. Of course, its exact L/D ratio would be governed, like the R.38 dimensions were governed, by the dimensions of the existing sheds. Sufficient strength, by the way, could be obtained with the 15-metre spacing, which would reduce the structural weight and also the weight of the gasbag fabric. In commercial units it was not necessary to have so many individual gasbags as in ships designed for war purposes, as one did not anticipate individual gasbag failure. He had been informed in Germany that the L.70 class were not suitable for commercial purposes, being built too lightly. They were designed to attain great height, and R.38 was designed to beat them. Captain Heinen informed him that he had reached over 8,000 metres (about four miles) during the trials of the L.71. In the proposed ship which he was trying to picture he would retain the streamline fins with the ordinary balance rudders. It would be better not to have the passenger car as far forward as in the Nordstern or Bodensee, but in a somewhat similar position to the R.36, because in the Nordstern and Bodensee it rather counteracted the effect of the vertical fins aft. This, he believed, was the principal reason why the Bodensee was considered the worst rigid airship built, from the passengers' point of view. By the way, a passenger cabin had been designed similar, in effect, to that of the R.36, but with far less resistance, and of rather simpler construction. It was actually prepared for a ship of R.38 dimensions, and hence would be entirely suitable for the proposed $2\frac{1}{2}$ million cubic feet ship. This ship would have a disposable lift, taking into account the more rugged design of, say, 46 tons, which, of course, would easily accommodate 40 passengers and 5 or 6

tons of mails, as Major Scott had indicated. As regards the gasbags, so long as we were not required to turn out ships every fifty or sixty days, like the Germans did, he did not think we need worry too much about the lack of goldbeaters' skins. The selected skins that we had been using recently, and had obtained without undue trouble, had averaged 7 to the square metre against 21 to the square metre in the old cases, and the cost of cleaning and scraping these skins was about one-third, and although these new skins cost double what the old ones did, the total manufacturing cost was only about 60 per cent., and supposing we were turning out as many as four ships a year, it would not seriously affect the goldbeaters' skin-market. It was fully agreed that all energy should be put into obtaining a synthetic substitute, but he wanted to emphasise the point that the lack of this substitute did not prejudice airship construction to-day. The gasbags that could be manufactured had an extraordinarily low permeability and a life of at least two years, if treated with ordinary care, as stated by Major Scott. As regards engines, it was a pity we had not been able to instal some of the new 260 h.p. German Maybachs handed over to us last year, because more experience with them would have been very valuable. Messrs. Sunbeam, however, had now delivered their 400 h.p. Semi-Sikhs, but we had not yet had an opportunity of trying them out on an airship. Although in an airship built to-day we should have to instal petrol engines, the danger from fire could be greatly minimised, if not entirely prevented, by excessive care in fitting the petrol system. This danger was the only one which concerned the German pilots. They had told him on more than one occasion that the simpler the petrol system in design and construction, the better they liked it, and it was one of the things they examined personally. In each of the ships, the construction of which he had supervised, he had always laid great stress on the tests that should be put on the petrol system, and he did not believe any ship had left his hands in which there had been the slightest weep at any joint or connection. It was essential that any sign of a leak should be immediately dealt with. Particular attention should also be paid to the slinging of the petrol tanks, so that in the event of an excessive inclination they would not break loose. This could easily be effected even in conjunction with the slipping devices. With regard to the fabric, he believed that "B" cotton outer fabric, with Farnborough dope, was sufficiently good at the present time, as in the case of accident or undue wear it could be easily replaced in sections. In all these points he was dealing with matters raised by Major Scott as really concerning a ship that we could put into the air to-day. He need not remark on mooring masts. Their advantages were obvious, but there were in hand modifications to the existing designs which he personally thought would afford considerable improvement. All his preceding remarks and general ideas for a suitable ship were useless without constructional experience. This, perhaps, most important item had been omitted by Major Scott in his résumé of the position to-day, but it was absolutely essential that personnel, skilled in construction, should be retained. Mr. Burgess would bear him out in that. He knew, as well as anyone, the art there was in girder-making. Enlarging on this point, one must not forget the nature of the alloy that was being used, the care that had to be taken in regard to heat treatment, and many other points which one could talk of from practical experience for many hours. Unfortunately, all our skilled personnel had practically been disbanded, and it would be rather difficult to gather a sufficient number together again. It would be a terrible mistake to lose the few that were left, and who could form the nucleus of another staff. This was a point of the utmost importance, and one which was generally forgotten by those who discussed airship subjects to-day. His own experience in supervising rigid airship construction, dating back to R.9 in 1915, had taught him the immense importance of shed and shop organisation, workmanship, and attention to detail. It was all very well to produce a design and demand materials of certain specifications and scantlings, but it would all signally fail if the shed and shop work failed. He wished to emphasise most strongly that conferences and committees

called to discuss airship matters should necessarily have a practical constructional representative, as well as a member with practical flying experience. As somebody said the other day, airships had come to be considered too much as a science and too little as an art. At first sight it might appear that his remarks had little bearing on the subject of the paper, but Major Scott had detailed out the principal items which together gave an airship, but had omitted that most important factor in development—the actual construction, except for a brief reference to the possibility of building a rugged ship to withstand all weathers and keep to a time-table. Perhaps Major Scott had such faith in the constructors that he did not feel it necessary to mention it, but in any case he personally felt compelled to urge that the practical constructional side, through not being so much in the limelight, perhaps, was too often overlooked in present-day deliberations, and no conference on the present situation, or committee formed to discuss future arrangements, was complete without a constructional representative—one who had had long experience and had come up against the many snags in the manufacture, erection and running of airships.

Commander F. L. M. BOOTHBY said that Major Scott had given a very fair paper on the position of the airship as it was in this country to-day. We had had three years now since the Armistice to acquire running knowledge and develop commercial airship lines all over the world, but had failed to grasp the opportunity, and all knew how we now stood. Others were going ahead. He had the pleasure about a fortnight ago to meet in Paris the Chairman of the Spanish-American Company, which was going to run airships from Spain to the Argentine, and he had very kindly told him what that Company was going to do. The Company had got its money and had made terms with the Spanish and Argentine Governments, and both Governments were going to repay the cost of their sheds over a period of 50 years. A subsidy had been arranged with the Argentine Government, and the airships would run direct from Spain to Buenos Aires. There were two Zeppelin directors on the Board, and they proposed to build ships of 150 to 180 tons, which was about double the size proposed by Major Scott. It was admittedly a big jump, but they had the knowledge to take that jump, and hoped in two years to have the service running. It was proposed to concentrate chiefly on mails, but they would take passengers at £150 a head from Spain to South America, or vice versa. He had spoken to prominent people in the Argentine and had been told that there would be as many passengers as they could carry, even at £200 per head. That was the most favourable route in the world as far as weather conditions were concerned, and should have been developed by this country had airships here been properly supported. That all went to show that Major Scott, in asking for a $2\frac{1}{2}$ million cubic foot airship for the Australian route, was not asking too much in view of the experience of the Germans with airships, and the steps they propose to take.

Colonel V. C. RICHMOND expressed the view that Major Scott had achieved his object in a most admirable and able manner, for he had given a clear estimate of what an airship could do from a technical point of view. There had been a lot of discussion as to whether airships should be employed for long-distance transport, and it was essential that we should put our house in order and be able to say concisely what was the ability of the airship from the technical point of view. Mr. Burgess had remarked that the airship was in a somewhat precarious position, but he could not help feeling that Major Scott, by this paper, had put it in a less precarious position. He invited everybody to read again the statement that "an airship of 75 tons could be built without introducing any experimental and untried features, that the hull would last in continuous service for at least five years, and would have a useful lift for freight of 12 tons, and could make non-stop journeys from England to Egypt at a speed of 50 miles an hour." That might be described as the airship's charter; one might almost say it was a pessimistic estimate; and how anybody could read that statement, go away, and not think

that we should immediately get on with the development of commercial airships, he could not imagine. They often heard that the airships had had £40,000,000 spent on them, but they would all admit that enormous technical strides had been made since the early airships were built. He would very much like to know whether it was possible to get some estimate of the money which had been spent in the development of the aeroplane. Naturally, there was more incentive for this during the war. Aeroplanes were able to do more useful work; nevertheless, it must be remembered that an enormous amount of money had been spent on their development, and it had been very difficult to get any money at all for airship development. Big improvements were in sight, bigger, perhaps, than any of them imagined. Major Scott had been most retiring in referring to this. In fact, he had almost left it out of the picture. Nevertheless, big improvements were in sight, and once there was the necessary incentive he was perfectly sure that English genius and English engineers would be capable of maintaining the lead which England once held—he was obliged to say “once”—in airship matters.

Mr. A. H. ASHBOLT congratulated Major Scott on having put more information into as few words as he had ever heard before on this one subject. With regard to the mooring mast, he was in Germany in 1912 and saw a fair amount of Zeppelin flying at that time, and he then realised that a possible future existed in that method of conveyance. From the commercial point of view, however, with which he was largely concerned, it was a wash-out when they took into consideration the large number of men necessary to start or load a ship, together with the fact that even with such a large number of men, the ships could only be utilised on fine weather days. When he came to England twelve months ago and saw what had been done in the way of mooring ships, he realised that their commercial possibilities were a distinct factor, and it ought to be recorded in the annals of the Society that the main factor—the mooring mast—in reducing this to a practical commercial proposition, was largely due to Major Scott, who, naturally, had not referred to it himself. On the commercial side, some of them knew that he had taken some little interest in trying to evolve an Imperial airship scheme, and when the Conference of Premiers was sitting in London last June, he managed to get this subject included in the agenda paper. Unfortunately he could not get the different Dominion Premiers, while in England, to put down a hard and fast statement of what they would do. He knew that the members of the British Government were sitting on the fence and were not anxious to do anything unless they were absolutely pushed by the Dominion representatives, but unfortunately he could not get the Dominion representatives to come down to a hard and fast proposition before they left. However, he had, during the last few months, been pegging away at the Dominion Premiers, and it was only last week that he got a second, or third, telegram from the Prime Minister of Australia, Mr. Hughes, saying that he was definitely bringing this matter before the Australian Parliament, and that he would do his best to push it through, and in that event he would put up a proposition to the British Government. Since his own paper on the possibilities of an Imperial service last week, he had had another telegram from Mr. Hughes—last night. It was of a confidential character, and he could not give details, but he could say this, that that telegram indicated every possibility of a definite proposition coming from Australia in the very immediate future. If they could get a definite proposition from the different Dominion Governments, he did not believe that the British Government could then fail to come along and join forces with their overseas representatives, and in that case, if they could only get sufficient money together, they ought to start an experimental service for a period, say, of two years. If in that period they could not justify the confidence which some of them had in airships, then it would be time enough to break up the whole organisation and pass it out. He, however, was not of that opinion. He was confident that if they could get the ground plant into existence and run through a few experimental airships so that the people in the overseas Dominions could see for themselves what had been

done in airship construction, there would then be no more doubt, and at the end of the experimental period it would simply be a matter of building ships which the experimental flights would have indicated as the most suitable. In view of the messages which he had received last week and the week before, there was every possibility of some definite proposition being put forward, and in that case it was to be hoped that we should be able to do something and not let England and her Dominions drop out of the airship competition, which unfortunately seemed to be the prospect when the Government, last August, decided to break up the personnel and the plant. He would like to congratulate Major Scott on the valuable information which he had given, information which, to commercial people like himself, was of great benefit, and would help them if they could only get the different Governments to come together and assist.

Squadron-Leader R. M. HILL said that he was an aeroplane pilot, and as there was a bond between aeroplane people and airship people, namely, the air, he took the opportunity of saying a few words. He quite agreed with Major Scott that the airship could do a great deal that the aeroplane could not. Most aeroplane people were immersed in aeroplanes from morning till night, and possibly got into a groove; but when one went to an airship station and saw what airships could do, and what they did do, and what they had done, and what he hoped they would do, then one became confident that the present lapse was purely temporary. He went up to Howden about a year ago and was taken into R.33, and he must say that it was simply like stepping into fairyland. It was the most beautiful engineering structure that he had ever seen, and one could not help feeling that an engineering achievement of that sort must be useful in civil aviation.

He was very interested in what Major Scott had said with regard to airship engines. He spoke under correction, but he believed that most of them had been Sunbeams. These had been fitted into aeroplanes; they were what one would call a light engine, and were obviously unfitted for use in airships. It must have been a tremendous handicap to the airship people not having a good, heavy, solid, economical sort of engine to work with, such as the Germans used in their own airships. He would like to ask Major Scott one point, and that was—when he was using his instruments to make observations of heavenly bodies, was the view obscured owing to the control car being underneath the body of the airship?

He remembered hearing the late Air-Commodore Maitland give his unforgettable lecture on the voyage of the R.34. Air-Commodore Maitland, as they knew, was the mainspring of the British air service, and he gave the lecture in cold, measured terms, and half-humorous chat from a log-book. To himself it was an exciting drama, with Major Scott as the central figure. Major Scott, having done what he did, was certainly the most able man to impress everybody with the possibilities of the airship, and not the least, aeroplane pilots; and he hoped that in future the airship and aeroplane would go along side by side and be a mutual help to each other.

The CHAIRMAN said he supposed that most aeronautical engineers had been asked as to their creed about airships. He had been asked "Do you believe in airships?" and he proposed here and now to say publicly "I do." It helped when people associated with aeroplane work definitely said that. He added a proviso, however, that if we stopped our research work, the existing structure of our knowledge would practically vanish. If the Geddes Committee, for example, prevailed on the Defence Minister to cut the present modest expenditure on aeronautical research, then all the rest of their air expenditure would be wasted, there would not be any progress in this country, and the technical position now held would pass to America or some other country. Research was the foundation; the visible and apparently more useful superstructure would collapse without that foundation. The public would probably hear of research being struck off without a qualm. They could not see what they would be losing, and if the

foundation were maimed, then he did not believe in airships in England. Years ago he had a pleasant airship cruise for six hours in the *Victoria Louise*. That was in 1912. That did not fill him with a conviction that he knew all about airships; quite the contrary; but one could not live for six hours in an airship without thinking hard about their use, construction and future. He generally found that those who did not believe in airships knew nothing about them. Why had not airships progressed more rapidly as compared with aeroplanes? The answer was partly "money," and partly that experimental construction was slow, and partly that the research side had in the early stages been inadequately appreciated. The number of experiments one could make in a given time with airships were tens against hundreds or thousands with aeroplanes. The number of experiments we have in fact made is only a fraction of the number we could have made with the airships at our disposal. That was an error of perspective in his opinion on the part of the Air authorities in the past. Had we pressed on the research side, we might, without any difference of total expense, have had that capital remuneratively expended.

Major Scott had drawn attention to the change which came about with increase of airship size and speed from the time when there was a predominance of static load in the basic designs of airships and the time when there was a predominance of dynamic load. With the increase of speed and the invention of the mooring mast, a great change came over many people's views; many who a few years before did not believe in airships as a means of transport because they could not deal with moderately high winds began to feel that the position was altering. Not only had airships flown at 70 miles an hour, but a 70-miles-an-hour wind was a rare occurrence. He felt that they might accept Major Scott's view to be justified in that we could count on a useful travelling speed of something like 50 miles an hour from place to place.

With regard to goldbeaters' skin, he had been associated with the use of goldbeaters' skin for balloons, and we in this country were responsible for the development of the use of goldbeaters' skin, which was twenty-four times better than rubbered fabric for keeping the hydrogen in the bag. Then the Germans got hold of goldbeaters' skin, and the price went up many, many fold; from one sovereign, the price went up to three or four when the Germans started using them. However, he was glad to hear someone say in the discussion that they did not think the amount of goldbeaters' skin used would be such as to seriously affect the price even if we built three or four airships a year. Possibly that was true, and so much the better. He happened to be aware of some remarkable and extremely interesting progress that was being made in the study of gelatines, from which much was to be hoped. He supported what Major Scott said as to the progress that was being made and as to the possibility of gelatine taking the place of the expensive goldbeaters' skin. He did not go so far as Major Scott in regard to the danger from fire due to petrol. Some interesting experiments had been made, and there were some people present who knew about them and could say that he was not exaggerating. The danger of fire, so far as petrol would cause it by flowing over hot exhaust pipes, was less than was usually thought. He did not mean by this that one could go and light a pipe over an open petrol filler, but the danger from petrol dropping on to a hot exhaust pipe, or even on to the hot ash of a cigar, was less than was commonly thought. On the other hand, a little bit of cotton fluff dropping on to that same hot pipe would light, and if it did so, its flame would ignite the petrol there. The impression that risk arose directly from the petrol was all that he was controverting. He accepted what Major Scott urged, namely, that they need not be afraid because there was a big bag of hydrogen above them.

Lastly, he would like to point out just for the sake of old times and for the sake of the old aircraft factory, of which he was very proud, that the first airship that ever swung from a mooring mast clear of the ground or water was

invented, designed and made at Farnborough by the old Royal Aircraft Establishment of that day. They hung out their airship for two or three months. It turned out to be quite an important thing. With regard to Mr. Ashbolt's very interesting remarks, what was in his mind was that we must link up with the Colonies, and that link was fundamental to the Entente with them. If we did not have airships, high-speed sea ships would have to be available to link us up more rapidly and connect us more freely with our Colonies, but there was no doubt that airships would be a cheaper and quicker means of travel.

Major SCOTT, replying to the discussion, said that the taking of sights on an airship with the sun and stars was done from the top. There was a platform which was approached by a ladder up the centre of the airship, and the sights were nearly all taken from the top, so that there was a perfectly clear view. He absolutely agreed with Mr. Burgess that they must combine forces at the present time. The airship was one of the most important forms of transport for the future, and transport, as somebody said, was civilisation. At the present time there was a Conference at Washington and the League of Nations, all tending towards civilisation; anything to improve the transportation of the world was doing the same thing, and therefore they must all combine in the development of aerial transportation. Commander Cave-Browne-Cave had accused him of being pessimistic. He was glad he did. He had given them in the paper what he considered to be the absolute true facts of the case at the present time. He had not given them his opinion; his opinion was much more optimistic. He had merely given them facts which he could absolutely confirm. There was nothing in what he had said that was the slightest bit questionable, and the speeches made by Commander Cave-Browne-Cave and others had shown that what he had given was actually pessimistic, and that the Chairman's view was very much in the other direction. The airship mentioned by Mr. Wynne-Evans would suit him very well. If he were given an airship like that, he had no doubt that he could carry out Mr. Ashbolt's scheme without any trouble whatever. If he were to start discussing the question of the disbanding of the skilled personnel, he would never stop; but, as the Chairman had said, this paper was a technical paper and not a political one. He was very pleased with what the Chairman had said about petrol. He had not wanted to impress anybody by what he had said in the paper that the danger of fire was big. He had merely wanted to say that that was the biggest danger, and the Chairman had now told them that that danger was not big. He wished them to judge the danger of the airship from that statement.

A hearty vote of thanks was accorded the author.



PUBLICATIONS.

The following papers, etc., are published by the Society:—

Transactions.

1. "The Calculation of Stresses in Aeroplane Wing Spars," by Arthur Berry, M.A. ... 5s. od.
2. "Position Fixing in Aircraft during Long Distance Flights over the Sea," by Instructor-Commander T. Y. Baker, R.N., and Major L. N. G. Filon, D.Sc., F.R.S., late R.A.F. ... 5s. od.
3. "Aero Engine Efficiencies," by Dr. A. H. Gibson ... 5s. od.

Aeronautical Classics.

Reprints of the Work of Early Pioneers on whose theories modern flight is based.

1. "Aerial Navigation," by Sir George Cayley (1809) ... 21s. od.
2. "Aerial Locomotion," by F. H. Wenham (1866) ... 1s. od.
3. "The Art of Flying," by Thomas Walker (1810) ... 1s. od.
4. "The Aerial Ship," by Francesco Lana (1670) ... 1s. od.
5. "Gliding," by Percy S. Pilcher (1897) ... 1s. od.
6. "The Flight of Birds," by G. A. Borelli (1680) ... 1s. od.

Miscellaneous Publications.

- "Steels Used in Aero Work," by Dr. W. H. Hatfield ... 5s. od.
- "Methods of Measuring Aircraft Performances," by Captain H. T. Tizard ... 1s. 6d.
- "The Screw Propeller in Air," by M. A. S. Riach ... 2s. 6d.
- "The High Tension Magneto," by A. P. Young ... 5s. od.
- "Commercial Aeronautics," by G. Holt Thomas ... 2s. 6d.
- "The Training of Aeronautical Engineers," by R. M. Walmsley and C. E. Larard ... 2s. 6d.
- "Steel Tubes for Aircraft," by W. W. and A. G. Hackett ... 2s. 6d.
- "Timber," by W. H. Barling ... 5s. od.
- "Design of Aeroplane Struts," by W. H. Barling and H. A. Webb ... 2s. 6d.
- "Stress Optical Experiments," by Major A. R. Low ... 5s. od.
- "Medical Aspects of Aviation," by Dr. L. E. Stamm ... 2s. 6d.
- "Struts of Conical Taper," by H. A. Webb and Miss E. D. Lang ... 1s. 6d.
- "Shop Practice in Respect to Aircraft Steel," by H. P. Philpot ... 5s. od.
- "The Rigging of Aeroplanes," by R. J. Goodman Crouch ... 5s. od.
- "Progress of Aviation during the War Period," by Dr. L. Bairstow ... 5s. od.
- "Flight of Seagulls," by Dr. E. H. Hankin ... 5s. od.
- "Chronology of Aviation," by H. Maxim and W. J. Hammer ... 1s. od.
- "Report of the Bird Construction Committee" ... 10s. 6d.
- "Glossary of Aeronautical Terms" ... 2s. 6d.
- "London-Paris Service. Safety and Economy Committee's Report" ... 1s. 6d.



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Notices of the Royal Aëronautical Society.

Applied Scientific Research.

On another page will be found a memorandum directed towards the safeguarding of applied scientific research in aeronautics which was drawn up by the Council and laid before the Secretary of State for Air (Captain the Honourable F. E. Guest, M.P.) at an interview on January 17th by a deputation consisting of the Chairman (Lieut.-Col. Mervyn O'Gorman), Prof. L. Bairstow, Sir Mackenzie Chalmers, Prof. B. Melville Jones, Colonel Alec Ogilvie and the Secretary.

Lectures.

Dr. Pullin's lecture having been postponed from February 2nd to March 16th, the next meeting will take place on Thursday, February 16th, at 5.30 p.m., at the Royal Society of Arts, John Street, Adelphi, when Squadron-Leader C. F. Portal will read a paper on "Methods of Instruction in Aeroplane Flying."

Air Conference.

The following members have been nominated to represent the Society at the Air Conference to be held in the Guildhall, London, on Monday and Tuesday, February 6th and 7th:—Dr. L. Bairstow, Wing-Commander Cave-Browne-Cave, H. Glauert, Major F. M. Green, Capt. G. de Havilland, Squadron-Leader R. M. Hill, Prof. B. Melvill Jones, Major D. H. Kennedy, Major A. R. Low, Lieut.-Col. W. Lockwood Marsh, A. Ogilvie, Lieut.-Col. M. O'Gorman, Dr. A. J. Sutton Pippard, A. V. Roe, Sir R. M. Ruck, Major G. H. Scott, R. V. Southwell, H. L. Stevens, H. T. Tizard, Major H. E. Wimperis, R. McKinnon Wood.

R.38 Memorial Research Fund.

The Council have appointed a Committee, consisting of Professor L. Bairstow, Wing-Commander T. R. Cave-Browne-Cave, Major R. V. Southwell and Major H. E. Wimperis, to consider the administration of the R.38 Memorial Research Fund. The following further donations to this fund have been received since the

publication of the last list in the December issue of last year, bringing the total up to and for 23rd January, 1922, to £1,202 17s. 10d. :—

	£	s.	d.
12th Squadron, Royal Air Force	43	7	3
V. Stefanson, Esq.	10	0	0
Griffith Brewer, Esq.	10	0	0
2nd Squadron, Royal Air Force, Fermoy	9	0	0
47th Squadron, Royal Air Force, Helwan, Egypt	7	11	7
Sir Mortimer Singer	5	0	0
70th Squadron, Royal Air Force, Heliopolis	4	17	0
Squadron-Leader D. Harries	2	2	0
Mrs. N. G. H. Hodgson	2	2	0
G. Reid, Esq.	2	2	0
S. Payne, Esq.	2	2	0
A. E. L. Chorlton, Esq.	2	2	0
Inspector-General W. Gwatkin, Canadian Air Force	2	2	0
Mrs. K. Reed	2	0	0
Major C. F. Abell	1	1	0
Colonel Ivan Davson	1	1	0
Flying Officer J. S. G. Wrathall	1	10	0
Flight Lieut. H. C. Irwin	1	1	0
A. E. Marsland, Esq.	0	10	6
Total	£109	11	4

Examinations.

It would greatly assist the Council in making the necessary arrangements if intending candidates for the Society's Associate Fellowship examinations, to be held in April next, would send in their names provisionally as early as possible.

Foreign Publications.

By arrangement with the publishers, arrangements have been made for copies of the French publications "L'Air" (1s. 3d. post free), "La Technique Aéronautique" (6½d. post free) and "L'Indicateur Aérien," to be obtainable by members at the Society's offices.

Arrangements for the Month.

- Feb. 1, 2.0 p.m. Candidates' Committee.
 2.30 p.m. Special Meeting of Council.
 „ 7 and 8. Air Conference at the Guildhall.
 „ 16, 5.30 p.m. "Methods of Instruction in Aeroplane Flying," by
 Sqdr.-Ldr. C. F. Portal, at the Royal Society of
 Arts.
 „ 21, 4.0 p.m. Library and Publications Committee Meeting.
 4.30 p.m. Candidates' Committee.
 5.0 p.m. Council.

W. LOCKWOOD MARSH, *Secretary.*



THE IMPORTANCE OF RESEARCH IN AERONAUTICS.

The following is an epitome of the views of the Council of the Royal Aeronautical Society on the need for better safeguards to prevent the submerging of applied scientific research in aeronautics by technical *ad hoc* experimental work. These views were laid before the Secretary of State for Air at a recent interview by a deputation of the Council consisting of Colonel M. O'Gorman, C.B., D.Sc. (Chairman), Professor L. Bairstow, C.B.E., F.R.S., Sir Mackenzie Chalmers, K.C.B., C.S.I., Professor B. Melvill Jones, A.F.C., and Lieutenant-Colonel A. Ogilvie, C.B.E. :—

The Royal Aeronautical Society's Council asks to be allowed to put before the Air Minister in person certain views which have been borne in them in relation to applied scientific research in aeronautics. They would lay before the Minister the standing of the Aeronautical Society and its quality to approach him on technical matters.

Four bodies represent British aeronautical activity, and these bodies respect each other's domains and are connected by agreements and joint committees—they are :—

- (a) The Royal Aero Club, concerned with the control of races, competitions and touring, the international sporting and touring rules and triptyques.
- (b) The Air League of the British Empire, concerned with propaganda, mainly in the interests of aerial defence.
- (c) The Royal Aeronautical Society, whose province is the spread of the study of aeronautical technics, both in theory and practice, including those branches of physics, chemistry, etc., which relates to aeronautics—as well as scientific research and publications therewith. This Society is officially represented on the Aeronautical Research Committee of the Air Council.
- (d) The Society of British Aircraft Constructors, the organised body of British constructional firms. The technical staff of the last are, in significant numbers, members of the Royal Aeronautical Society.

Applied scientific research has in England for one reason or another suffered from serious and increasing disabilities since the earliest flight. These disabilities arose from many causes, but notably from the fact that though research has forced itself into public recognition as fundamental to any technical advancement, when it comes to the detailed allocation of time and work this recognition becomes blurred by reason of other factors, technical, administrative, and financial, which tend to obscure its fundamental importance and crowd it out of existence. The occasional and (we venture to suggest) incorrect usage of the term "research" as a comprehensive name for all and any experimentation in aeronautical technics has led to its use to cover matters other than the true "applied scientific research" to which it is the object of the Royal Aeronautical Society to draw the Minister's attention.

"Aeronautical technics" (or research so-called) embraces many sub-heads, thus not only—

(1) Applied scientific research (properly so-called) whether theoretical, model or full-scale work, and referred to hereafter for brevity as Research,

But also

(2) *Ad hoc* experimentation and calculation on specific appliances, or proposals not forming part of an organised series.

(3) Experimentation to develop acceptable devices into standard useful appliances.

(4) The improvement of such devices in accordance with the demands arising from use and the introduction of modification specified for service reasons.

(5) Tests of performances of normal purchases for service.

(6) Etc.

This list may be extended . . . the above sub-heads are intended to be illustrative and not inclusive.

In a number of cases there is no confusion between what falls under one or another of these sub-heads; but there are limiting cases, when a form of words intended to lay down what is and what is not applied scientific research would lead to discriminating wrongly between research and other sub-heads.

The desire of the Royal Aeronautical Society is to ensure, if possible, the continued and urgent prosecution of Research as above defined. This is the Society's main plea.

As regards *method*, the Society hopes to give point to the above request by certain suggestions for the consideration of the Air Minister.

If the question of an organisation to deal with the matter be now considered we find that on the one hand all the heterogeneous activities above enumerated as aeronautical technics, which often have little in common except the fact that they are susceptible of being called "technical," might be ascribed, as and when they arise, to the same chiefs, the same sub-section of the money vote, dealt with by the same staff, and in the same establishment; or on the other hand, if one of them appeared to be of basic importance it might be specifically protected from encroachments.

These encroachments are natural, are known to occur in technical organisations having this diversity of interests and are easily explained, none the less they are difficult to guard against. They have been observed both in this country and abroad where for any reason *ad hoc* experimentation and applied research are in juxtaposition—which implies competition for the use of the time and services of the same staff. Thus, each *ad hoc* experiment which presents itself as desirable, and such always looks desirable or it would not be touched, (for example, the verification of some particular wing shape or wing thickness, put forward by an enthusiast or maker as having exceptional merits) appears to call for prompt attention; it seems to offer a royal road to results; the experiment would appear to be one of which the end can be foreseen and the amount of expenditure estimated; while the answer which the experiment affords will apparently be either positive or negative, but in either case useful.

In contrast, Research (for example, the investigation of aircraft control at low speeds, of pressure distribution on wings, of the twist and vibration of airscrew blades in flight, or the control of aircraft from the ground at night or in fog) is rarely backed by the pressure of an enthusiast who vaunts the advantages of his specific device, nor is it clear how long such an investigation will have to be prosecuted; still less what important side issues will have to be explored before its harvest of results can be expressed in terms of actual aircraft.

The administrative head thus finds himself confronted on the one hand (A) by a number of requests for research, of which he cannot foresee either the exact end, the total cost or the exact resulting advantage, and (B) with demands for the verification of the alluring claims of some particular device; while, and in addition to the above conflicting demands for technical attention, there are (C) the service demands for introducing improvements in existing, and standardisation of proposed, technical appliances, and other kindred matters. The plea of the Council of the R.Ae.S. is that, particularly in a time such as the present of

reduced expenditure, the position of Research as above defined shall be *specifically* safeguarded in some manner. Throughout the war it was openly urged that *ad hoc* experiments must take precedence of research, and there is no doubt but that they did so—an attitude with which the Royal Aeronautical Society is in full harmony. Prior to the war much the same result was to be observed, for reasons which need not be entered upon at the present time. In the post-war period analogous troubles are liable to arise. The Royal Aeronautical Society urges upon the Air Minister that research is the fertiliser at the root of the tree of progress; without it the tree will not only fail to grow, it will die and all that will then be available is the standing wood.

The constructive suggestion which this Society puts forward to give point and practicability to its proposal for the safeguarding of Research in aeronautics, which is its main theme, is that a precedent found in the organisation of the Admiralty be followed in its general outline by the appointment of an individual of high scientific qualifications whose specific duty will be the safeguarding of Research, keeping it in touch with the scientific work of the country, and with the problems of civil and military aircraft. Those characteristics of the office in question, to which we wish to draw attention, are as follow :—

- (1) That a grant of money be specifically allotted to research, as above defined.
- (2) That the individual holding this office shall have access to the Members of the Air Council.
- (3) That he have access to private advice, and have money specifically available to him for the purpose of paying for such advice.
- (4) That there be an Advisory Committee external to the Air Ministry, consisting of scientific men. This Committee to have no executive powers and be solely advisory.
- (5) That this Committee should supervise and publish such matters relating to research as are deemed to be publishable in the public interest.

In addition to the above, the Council of the Royal Aeronautical Society trust that support will be continued to the movement for giving scientific training to selected officers of the Royal Air Force, so that highly-experienced pilots shall be able to suggest and intelligently take part in Research work—to which such assistance will be invaluable.

In conclusion, the Royal Aeronautical Society points out that any retrenchments of administrative staff or expenditure in construction form strong reasons for safeguarding that least expensive and most fruitful form of activity—Research.

It is, finally, desired to make it clear that the Service members of the Council have felt that their Service appointments debar them from expressing any opinion on this matter.



PROCEEDINGS.

FIFTH MEETING, 57th SESSION.

An Ordinary General Meeting was held in the Rooms of the Royal Society of Arts on Thursday, December 15th. Lieut.-Colonel O'Gorman, Chairman, was in the chair.

The CHAIRMAN, in opening the meeting, said that the Lecturer that evening was Major F. M. Green, with whose technical and scientific work they were all probably familiar. Any lecture from an engineer of his experience in his subject would well repay attention.

Major GREEN said that before giving the paper he wished to make one personal remark in which he would, perhaps, be anticipating criticism, and that was to say that he was not a pilot. His flying experience was limited to a very few very short flights on an old machine. He was certainly not a fighting pilot, and therefore he wished them to understand that the paper had been written from the designer's point of view, although he had tried to collect opinions from all the fighting pilots that it had been his privilege to meet. Perhaps on this occasion he would hide behind the proverb "Onlookers see most of the game."

Major F. M. Green, O.B.E., M.I.C.E., F.R.Aë.S., etc., then delivered the following lecture:—

DEVELOPMENT OF THE FIGHTING AEROPLANE.

There was perhaps nothing in aeronautics that developed so quickly during the Great War as the fighting aeroplane. At the beginning of the war the use of offensive weapons on aeroplanes was almost unknown. The idea of fighting in the air had hardly been discussed and certainly no country had made provision for carrying offensive weapons as part of the regular equipment of the aeroplane. Long before the end of the war every aeroplane was armed to a greater or lesser extent, while particular types of aeroplanes had been developed whose chief duty was the destruction of enemy aircraft and the protection of aeroplanes of its own country which were engaged in various specialised duties, such as reconnaissance and bombing.

In the truest sense of the word all aeroplanes used in warfare are fighting aeroplanes, but the scope of this paper is limited to those machines which are used primarily as weapons of offence against opposing aircraft.

Historical.

When the first aeroplanes were made, the actual flying was found of sufficient difficulty to make the thought of carrying out any special duties remote. As the knowledge of aeronautics increased, it began to occur to designers that the uses to which the aeroplane would be put in war might influence the design. At first it was thought that if one passenger were carried and a fairly good view of the ground were obtained, then the rest of the designer's energy could be devoted to improving the safety, reliability and speed of the aeroplane. It was this stage of development that had been reached when war broke out. The only offensive weapon that had been proposed was a carbine carried by the observer in a two-seated aeroplane.

The idea of an aeroplane solely for offensive purposes had not been seriously considered. Single-seated aeroplanes of fairly high speed had been made and in

England they were generally called Scouts. The general idea was that such aeroplanes should obtain information as quickly as possible, and I do not think that the idea of using them offensively to attack opposing aircraft was in any case the basis for their design. The most notable examples of these types of aeroplane in this country were the Bristol Scout, the Sopwith Tabloid, and the series of aeroplane with the prefix S.E., designed and made at the Royal Aircraft Factory as it was then called. The first of these machines was produced at Farnborough and first flew about the spring of 1911. It was known as the S.E.1 and attained a mean speed of 90 miles an hour flying near the ground over a short course. Various developments of these aeroplanes were made in the time preceding the war, and in the early summer of 1914 an aeroplane, which was to all intents and purposes purely a racer, was tested at Farnborough. It is interesting to note that this machine was fitted with flaps the complete length of the wings, so arranged that the angle could be altered during flight in order to decrease the landing speed. It was intended that this machine should go overseas with the expeditionary force, but it was damaged in a trial flight and it was not considered worth while repairing it. It must be remembered that none of the machines hitherto mentioned were fitted with guns of any sort and as weapons of offence they were of no value.

The aeroplanes that accompanied the British Expeditionary Force were almost entirely of the B.E. and Maurice Farman type, both of which are so well known as to require no description. It very soon became apparent that fighting in the air would become a serious business, and all sorts of gun mounts were devised which were to carry the Lewis gun. On the B.E.2 aeroplane it was usual to fit no less than five different mounts on which the gun could be supported, so as to make it possible to defend the aeroplane from as many points of attack as possible. In this aeroplane the observer sat in front of the pilot and this considerably increased the difficulty in obtaining good shooting.

At the beginning of the war firing through the propeller was unknown, and therefore on a tractor aeroplane the airscrews blocked out a large amount of useful field of fire. In order to get over this difficulty it was decided to develop a pusher aeroplane so that the gunner could have an unrestricted field of fire forwards. Three service aeroplanes were produced, two at the R.A.F. and the other designed by Captain De Havilland at the Aircraft Mfg. Co. The F.E.2 type was a two-seater aeroplane and the D.H.2 and the F.E.8 were single-seater fighters, made solely for offensive purposes. It was originally intended to make full use of the field of fire by providing a gun mount which enabled the pilot to fire in all directions forwards. It was found to be of little use on the single-seaters on account of the difficulty of manœuvring the aeroplane and the gun at the same time, and eventually a gun mounting was used which allowed for elevation only. Both types of the single-seater pusher were successful for a time and the F.E.2 had a long period of usefulness, though the later part of it was used more for general utility work than for offensive fighting.

Soon after the war started the usefulness of the speed of tractor aeroplanes became apparent, and the need for firing straight ahead became urgent. The first method used was to fix hardened steel deflector plates on the propeller blades so that the bullets which did not pass between the blades were deflected without damaging the airscrew. This worked fairly well, but added considerably to the weight of the propeller. It was soon superseded by a synchronising device which timed the bullets to pass between the blades. Various gears were used, some mechanical, others hydraulic, the latter type being adopted by the British Air Service. The result of the use of these devices was to establish the tractor aeroplane as the most useful offensive fighting machine and the small pusher type was altogether superseded. Although this policy was no doubt correct with the conditions as they were, it is by no means certain that the future development of small fighting aeroplanes will be solely of similar type.

Towards the latter part of the war the usefulness of two-seater aeroplanes for offensive work became apparent. If it were possible to develop training to a sufficient degree to get a real understanding between the pilot and the gunner, then there is little doubt that this type of aeroplane might compete very seriously as an offensive fighter with the single-seater. It must not be forgotten, however, that an aeroplane that carries one man is more economical than one which carries two men, and that the two-seater fighter must prove itself definitely more effective than the single-seater before its use for offensive purposes can be considered.

A number of single-seater tractor aeroplanes were made, generally of the biplane type, while both monoplane and triplane were used to some extent. The size of aeroplanes gradually went up until the standard single-seater machines weighed 1,700 to 2,000lbs. fully equipped, with horse-powers from 150 to 200. Since the end of the war aeroplanes with still higher performance have been developed weighing about 2,100lbs. and equipped with 300 h.p. engines.

This historical survey is very brief and has been mentioned more with the idea of suggesting future developments than with the intention of putting on record the history of the fighting aeroplane during the Great War.

In considering the future development of fighting aircraft we must bear in mind that there are a number of different kinds of war and that the requirements of each kind are separate and distinct. It obviously is no use having aircraft specially designed and equipped for fighting enemy aircraft if the enemy have no aircraft to fight. Highly developed single-seater aeroplanes, therefore, are no use whatsoever in savage warfare. Again, the performance required of the fighter aeroplane depends chiefly upon the performance of the aeroplanes to which it is in opposition. If the enemy aircraft are not first rate then it is more economical to use a slightly slower fighter of more general utility than to use the fastest and most finely down machine that can be produced.

The single-seater fighters, therefore, will only become of great importance for first-class wars, and it is essential that their design shall always be at least as advanced as the aeroplanes of the enemy. It will always be possible to make a small machine carrying little load that is faster and more manœuvrable than aeroplanes designed for heavier duties, for whatever improvements may be made in aeronautics are likely to affect the one type as much as the other. The safest way to ensure development, therefore, is to aim at a performance which is appreciably better than the best aeroplane of a larger type that the designer himself could make. It is not possible to know exactly what other people are doing, but we can feel fairly certain that if a designer is capable of designing a good fighting aeroplane at all, he will also be capable of knowing what the best performance is likely to be on a larger machine.

Armament.

As the duty of the fighting aeroplane is to fight, the starting point for design should certainly be the armament, that is to say, the position and number of the machine guns or other weapons carried and the suitability of the aeroplane to enable the pilot to bring those guns into such a position that they can most effectively be used. Assuming for the moment that machine guns of the type used in the late war remain unchanged to any serious extent, then we have to decide the best number of machine guns to be carried, the amount of ammunition that should be taken and whether or not the guns should be fixed to fire straight ahead or whether we should attempt a bigger field of fire.

In air fighting the amount of time that the fighting aeroplane is in a favourable position to shoot at its opponents is likely to be very limited, and as accuracy of fire will probably never be great, it is essential to provide means for firing the greatest number of bullets during the favourable periods, or in other words, to have as many guns as possible which fire as rapidly as possible. On the other

hand, the length of time that the aeroplane will be favourably situated for firing at its opponent depends upon the relative performance and manoeuvrability of the two aeroplanes. Adding more machine guns and carrying more ammunition will increase the size of the aeroplane, and will reduce both its performance and its manoeuvrability. As in all other matters of engineering design, therefore, we have to effect a compromise. There can be no rule for predicting what this compromise will be in the aeroplane yet to be designed. All we can say is, that at the end of the last war the equipment consisted of two machine guns each firing at the rate of 1,000 rounds per minute and that the ammunition carried was about 1,200 rounds. In a more recent design it has been found possible to increase the ammunition to rather over 2,000 rounds. From the above considerations it can be safely said that anything which will increase the rate of fire in an aeroplane without increasing the weight will be a distinct advantage, and the writer thinks that this is one point in which we may look for improvement in the fighting power of future machines. It is convenient to use equipment similar to that which has been developed for land warfare, but at the same time it seems probable that the fighting power of our aircraft could be very much improved if a special gun were designed consisting of two, three, or more barrels in which the rate of fire was increased to perhaps twice that of the present equipment.

Hitherto we have only considered guns of the machine gun type. It is possible that advantage will be found in firing a bullet larger than those of the present calibre. It is also possible that guns will be produced firing something more of the nature of shrapnel. The writer prefers not to suggest development along these lines, but will content himself by remarking that whatever is produced must be small and light, otherwise the all-important power of dodging will be lost.

View.

Having now decided that we must get a maximum rate of fire consistent with other factors, the next point to which we must give attention is to enable the pilot to place his aeroplane in a position favourable for using his guns. The chief points to be studied to enable this to be done are the view that can be obtained from the aeroplane, the speed of the aeroplane, its rate of climb and ceiling and the manoeuvrability of the machine.

The question of view is of an importance that can scarcely be exaggerated. The fighting pilot not only has to seek out the enemy aircraft, but must also be able to avoid being attacked unawares. His ideal field of view would of course have no obstructions at all, and this is obviously impossible. It is important that such obstructions as are unavoidable shall inconvenience him as little as possible. Experience has shown that it is almost essential that his view of the complete upper hemisphere should be unobstructed; that he shall be able to see down vertically over the side of the machine, and ahead and downwards to as big an angle from the horizon as he is able to get. Various positions have been tried on tractor scouts. It is the writer's opinion that by far the best compromise is obtained when the pilot sits with his head in line with the chord of the top plane and not too close to it. The front of the fuselage should slope down towards the engine and the lower plane should be of as narrow chord as possible and have its trailing edge about vertically beneath the pilot. By this means the view in the upper hemisphere is unrestricted and the lower plane offers comparatively little obstruction (Fig. 1). In any case it is easy to dive the machine sharply for a moment in order to make sure that nothing is being hidden by the lower plane. It is obvious that a still better view could be obtained by having no lower plane; in this case the aeroplane becomes a parasol monoplane. Unfortunately it is not easy to make an aeroplane of this type without certain compensating disadvantages, and in fact such an aeroplane has not up to the present been particularly successful. The disadvantage of a comparatively narrow lower plane is small, while the

advantages from other points of view seem to make it worth while keeping to the biplane type.

Triplanes have been made and the narrow chord is of some slight advantage for view, but the fact that it is necessary to have three planes makes it impossible to obtain a view which is as good as in the type just described.

In an aeroplane designed by Captain De Havilland, known as the D.H.5, the pilot was actually in front of the top plane, and was seated over the bottom plane to achieve this result. The trouble with this for good visibility is that the view of the upper hemisphere behind the pilot is seriously obstructed. It is also rather worse for aerodynamic reasons.

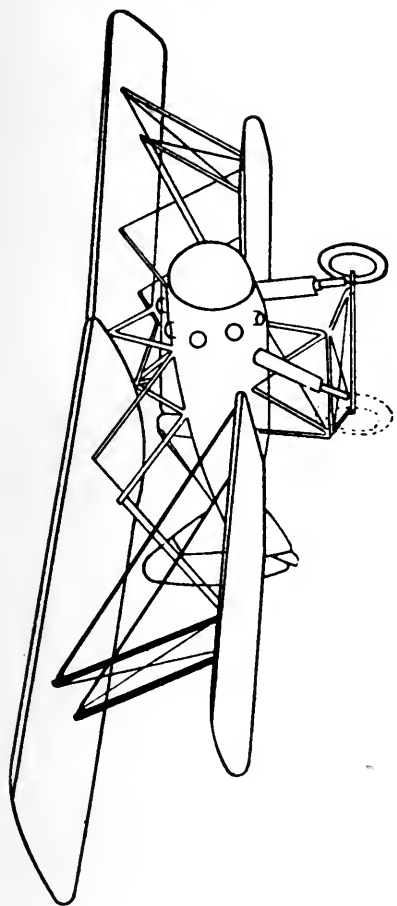
A third type of scout was also much used in which the pilot was placed as close to the engine as possible and was seated more or less underneath the top plane. For visibility this is not good, as the top plane obscures a large portion of the upper hemisphere. To avoid this a hole is sometimes cut in the plane, but this is only a partial cure and is bad for aerodynamic reasons. In certain cases the pilot's head is actually in a hole in the top plane. This certainly allows a good view of the upper hemisphere, but it is inclined to be awkward and is not popular with pilots, who seem to be afraid that if the aeroplane does turn over on the ground they will be in for a bad time.

The chief objection that is generally raised to seating the pilot behind the top plane is that the moment of inertia of the whole aeroplane is increased, and this makes it slow to manœuvre. For a long time it was claimed as one of the chief advantages of the rotary engine that it enabled the pilot to sit close up to the engine and produced an aeroplane which was extremely easy to manœuvre fore and aft. The writer thinks there are two fallacies in this view. Firstly, the increased gyroscopic effect of the rotary engine is equivalent to an increased moment of inertia of the aeroplane, and it can easily be shown that the decrease of moment of inertia is more than compensated by the gyroscopic moment. The other fallacy is that as it is always easily possible to manœuvre a small aeroplane fast enough in the fore and aft direction to break it, it is of no advantage to provide a quicker control than we have now without increasing the strength of the machine beyond what is practicable.

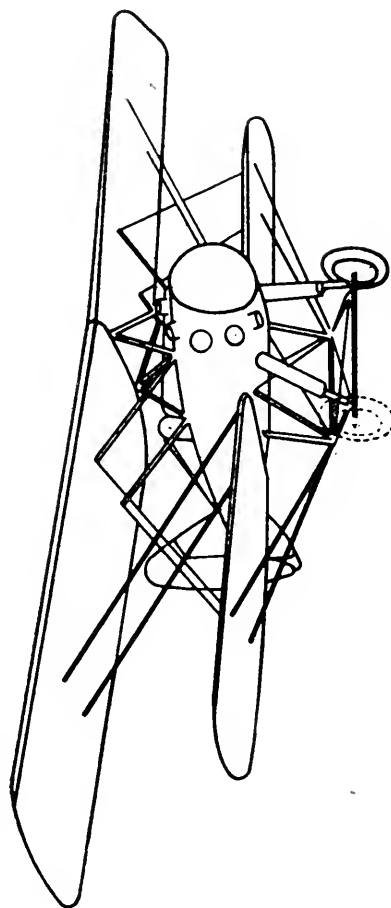
Ability to Withstand Damage.

The structure of the aeroplane itself is a large target in comparison with the pilot and the vital parts of the engine. It will be a big advantage if the aeroplane is so designed that it is likely to lose little of its structural strength when hit by the bullets of the enemy. Wooden spars are generally of such a section that many bullet holes are unlikely to cause sufficient damage to make failure in the air likely. There is always the possibility that a wire or the attachment of a wire will be shot away, and it certainly seems a requirement of the modern aeroplane that the structure of the aeroplane should not depend upon any single wire or attachment. Duplicating a wire by means of another wire alongside is apt to be dangerous as one bullet is likely to destroy both wires. The lecturer knows of one case in which an aeroplane partly collapsed when a bullet hit the point of attachment of two wires which left the plane at different angles. The ideal arrangement, therefore, is to make a structure which is braced by two or more independent systems.

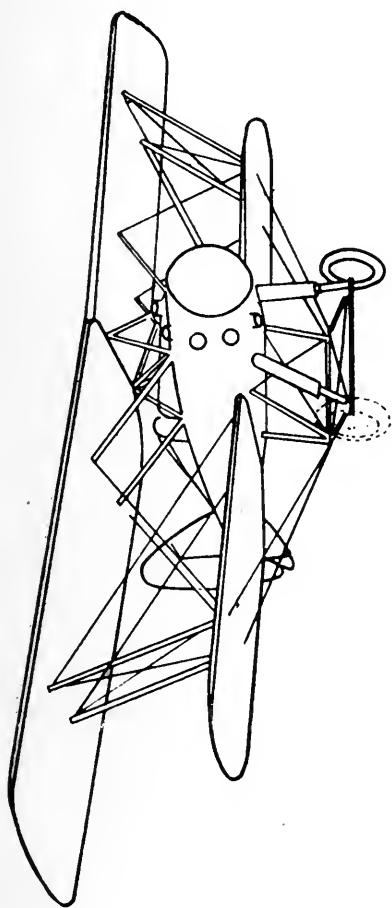
In the Siskin aeroplane, designed by the writer, the scheme of duplicated bracing has been carried out to a considerable degree of safety. It will be seen (Fig. 2) that the aeroplane is braced in the ordinary way by wires between the planes and that the wires are duplicated by the incidence bracing. In addition to the usual bracing there is a complete system of bracing to a king post under the body, which will give a fair factor of safety to the whole aeroplane if all the



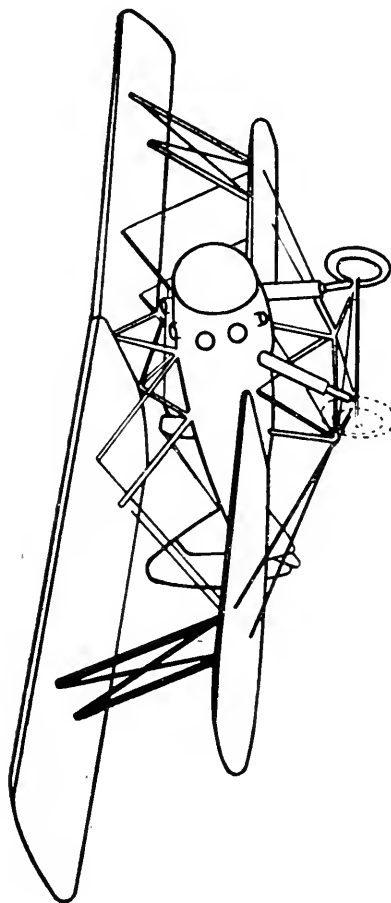
AUXILIARY BRACING SHOT AWAY.



STRUTS SHOT AWAY.



WING BRACING COMPLETE.



MAIN LIFT WIRES SHOT AWAY.

main bracing is shot away, so long as either the incidence bracing or the struts remain in place. We have in fact a structure in which the failure of any one wire increases the load on to two other wires. It seems reasonable to suppose that a structure of this type is very nearly safe from failure in the air from anything less than a direct hit by a shell.

As regards damage to the power plant, air-cooled engines certainly are at a big advantage in comparison with those which are water cooled. The danger of having the water system pierced is considerable, and although this does not immediately bring down the aeroplane, the loss of water will certainly mean a seized engine in a very short time.

Fire.

One of the greatest dangers to which a fighting pilot is subject is risk of being set on fire by an incendiary bullet. Towards the end of the war self-sealing tanks were introduced, which reduced this risk immensely. These, however, are rather difficult to make and add somewhat to the weight of the aeroplane. It seems possible that a similar effect might be obtained by surrounding the petrol tank with inert gas, as for instance cooled exhaust gas, and arranging to drain any accidental leakage of petrol overboard as effectively as possible. Unfortunately this would probably come out almost as heavy as the self-sealing tanks and would have the disadvantage that more petrol would be lost if the tank is hit.

Performance.

In order that a fighting pilot shall be able to choose the most favourable position when engaged in an aerial combat it is necessary that he shall always be able to outmanoeuvre his opponent, and at first sight it might seem that speed is the chief requirement. Experience has shown that rate of climb is the governing factor; the aeroplane at the greater height can always obtain extra speed by diving, consequently the aim of the fighting pilot is generally to outclimb his opponent. In addition to this, the ability to climb is also to a large extent a measure of the ability to manoeuvre rapidly at height, for it is necessary to have excess power to be able to turn quickly without losing altitude.

There are many ways by which ability to climb at high altitudes can be increased. The ratio of horse-power to weight can probably not be much increased as on certain aeroplanes this figure is no more than 7 lbs. per horse-power of the loaded aeroplane. Decreasing the wing loading in the general way increases rate of climb, but it has other disadvantages. The most promising way of increasing the ceiling and the rate of climb at high altitudes is to design engines which give the same or nearly the same horse-power at considerable heights as they do at ground level. This has already been done experimentally in this country and elsewhere. The most successful means up to the present is to provide a centrifugal type of air compressor which increases the density of the air supplied to the engine so as to keep it at ground level density. The extra weight of the gear is not very great and it is possible to maintain almost the full horse-power of the engine up to considerable altitudes. The same air compressor can be used to supply air at ground level density to the pilot, and thus the necessity for carrying oxygen can possibly be avoided.

By using air compressors there is really no reason why the ceiling of a Scout aeroplane should not be increased from rather over 20,000ft., as it is now, to 35,000ft. or 40,000ft. As it is probably too much to expect that pilots should fly at these great heights, the gear will be used rather to increase the rate of climb and manoeuvring power of the aeroplane at altitudes of about 20,000ft.

Manoeuvrability.

As we have seen in the last paragraph, manoeuvrability is largely a matter of performance. At the same time all aeroplanes with similar performance have

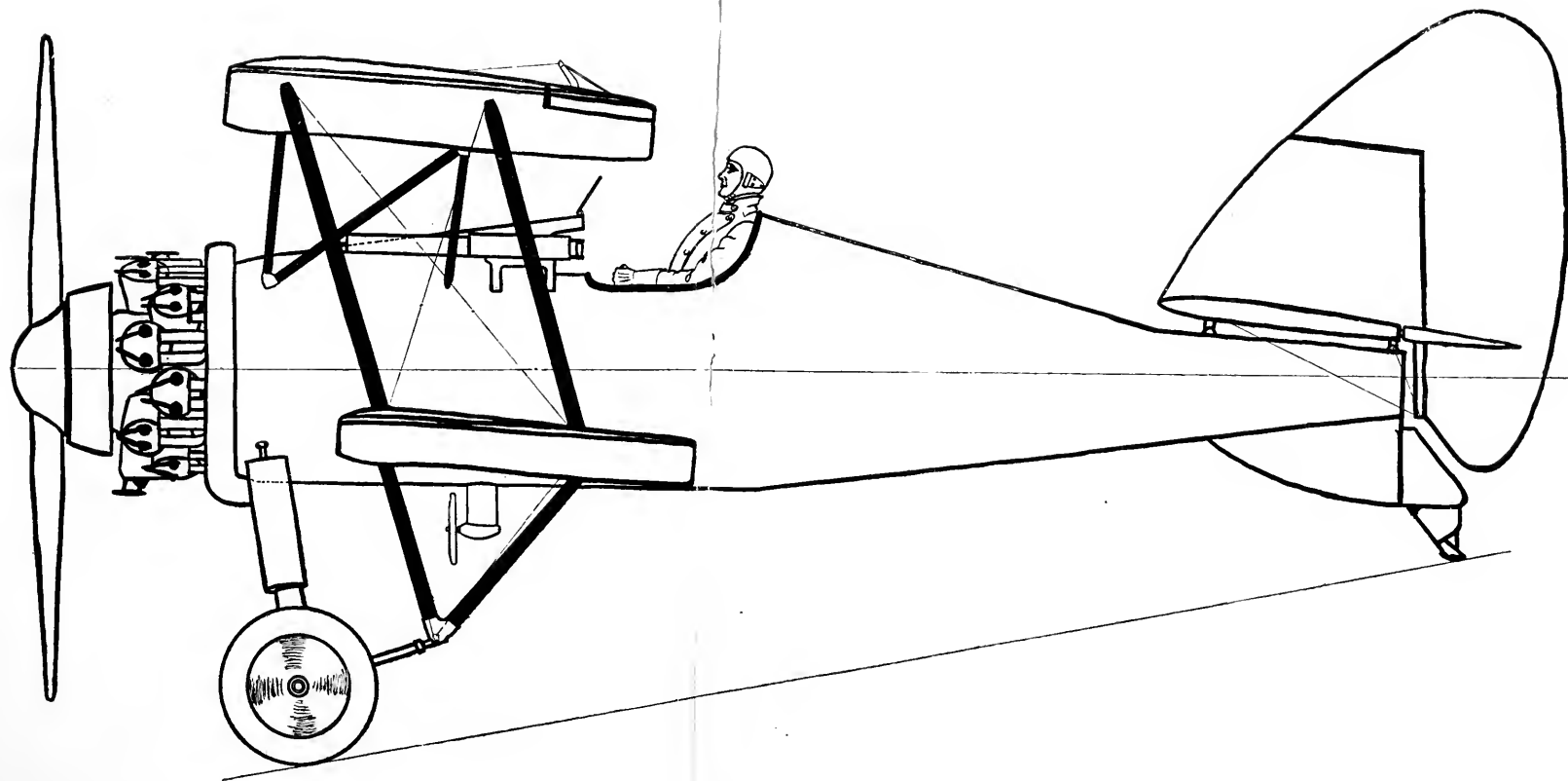
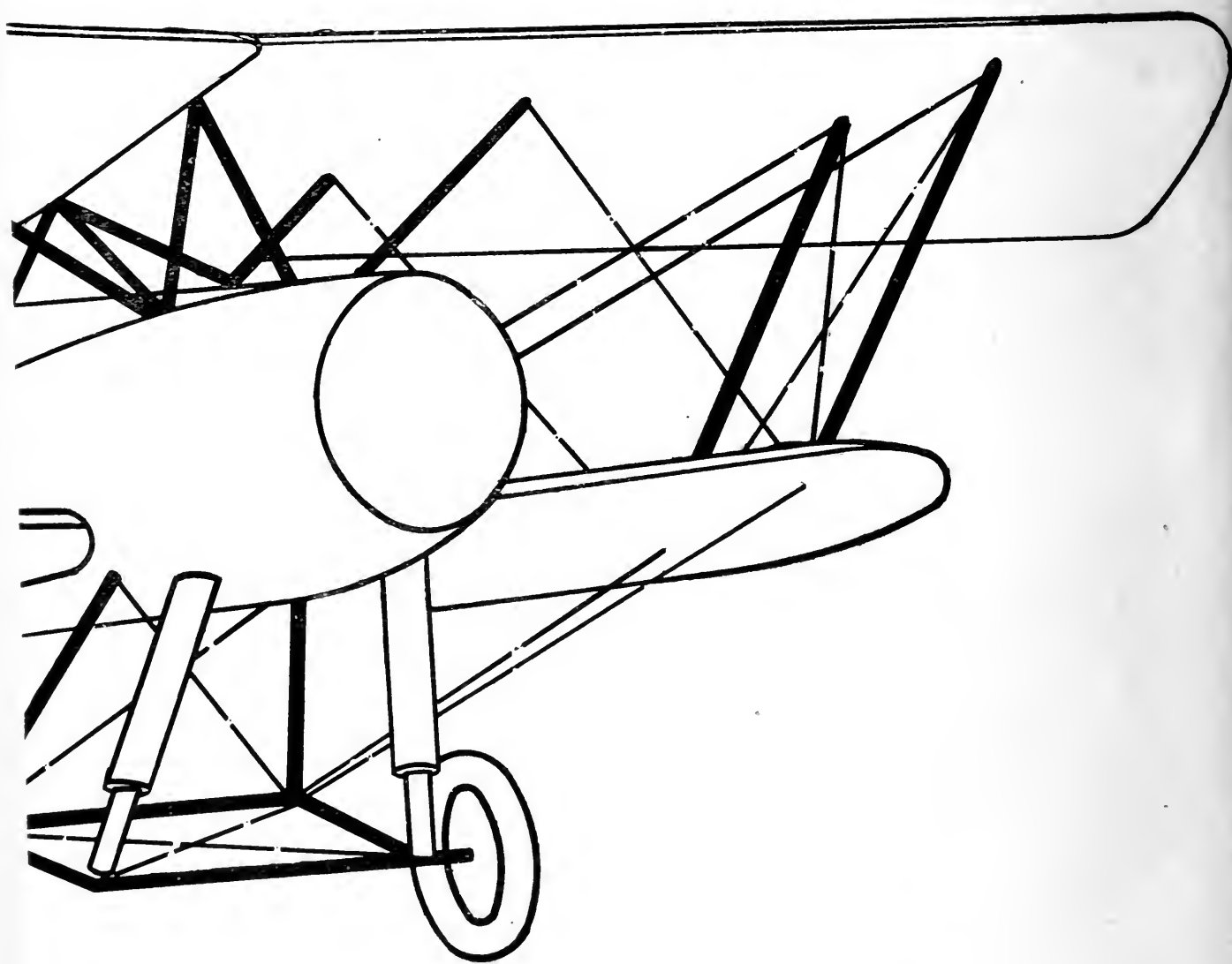


FIG. 1.



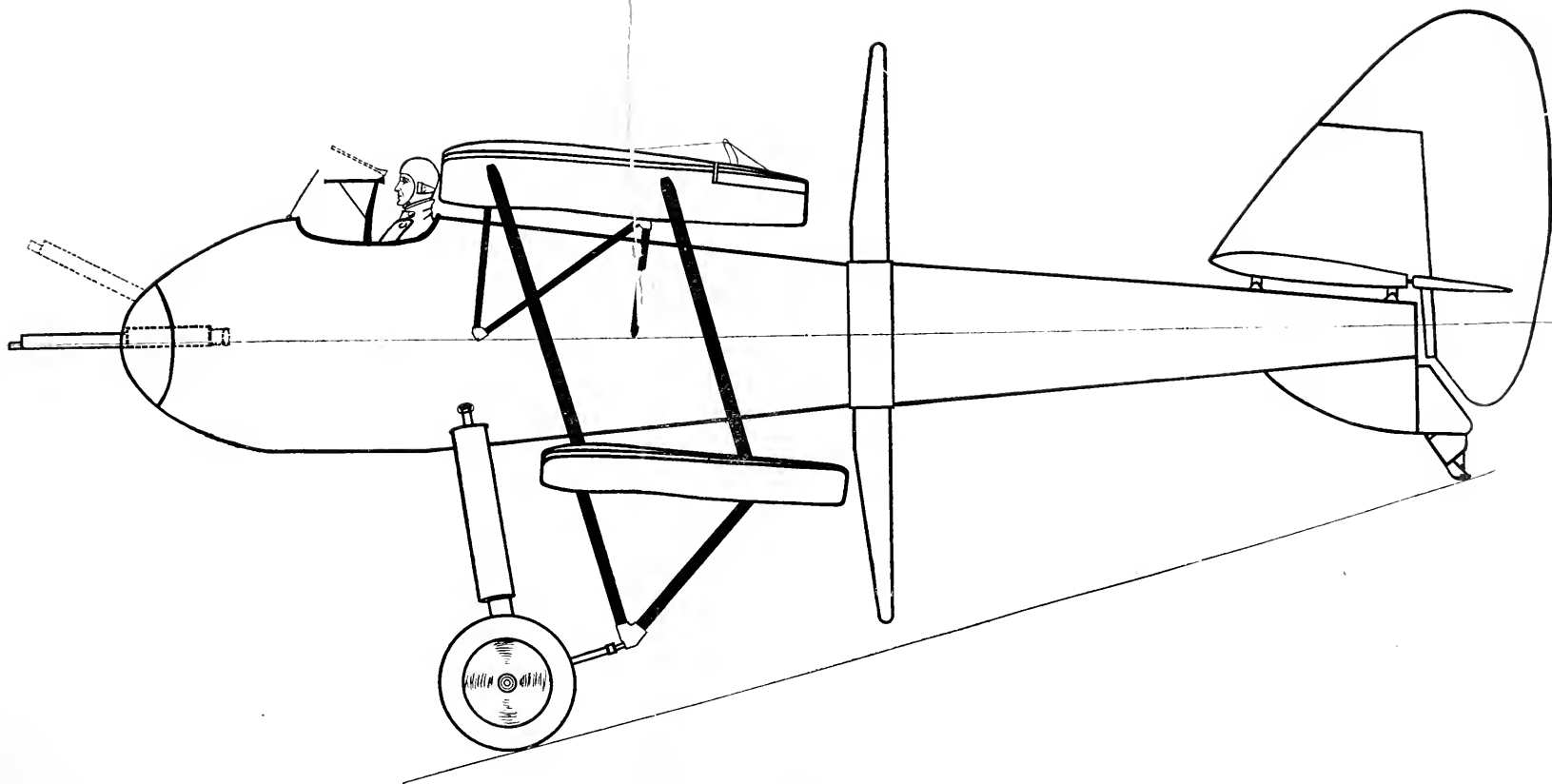


FIG. 3.

not equal power of manœuvring. It can easily be shown that the minimum circle in which an aeroplane can turn depends directly upon its stalling speed, hence the more lightly we load an aeroplane the more manœuvrable we may expect it to be. Unfortunately it is equally obvious that the more rapidly we manœuvre an aeroplane the stronger it needs to be; also the bigger the planes are, the heavier they will be. As usual, therefore, we have to arrive at a compromise which usually results in fighting Scouts being loaded from 7 lbs. to 9 lbs./sq. ft.

Experience of the late war has shown that there are two distinct and separate types of fighting. In the one the fighting pilot climbs to a height well above his intended victim and attacks in one long dive. If he misses he makes use of his superior speed and climbs to gain height and to repeat the manœuvre. The other type of fighting is that which takes place between aeroplanes which are very nearly equal in performance and frequently between large numbers of machines. In this case the aeroplanes manœuvre round one another at fairly close range, each endeavouring to get into a favourable position to fire at the other and to avoid being fired at in return. For this type of fighting the more lightly the aeroplane is loaded the better, while in the former type heavy loading is an advantage rather than otherwise. The heavier-loaded aeroplane will dive faster and probably be steadier on the dive, but it will be less able to turn quickly and fight well in what is generally called a "dog fight." During the latter part of the war fighting aeroplanes fell actually into two classes—those of the S.E.5 type, which were fairly heavily loaded, were used for the former type of fighting, and those of the Sopwith Camel type were chiefly used for the latter. Whether or not it is possible to combine both types of fighter in one aeroplane is open to question, but it certainly seems probable that an aeroplane designed to do for both classes of fighting will be less effective than one which is designed either for the one class of fighting or the other.

Two-Seater Fighters.

The case of the two-seater is much the same as the single-seater fighter, but the addition of the gunner makes it possible for the two-seater to fire in directions other than straight ahead. This to some extent makes up for the somewhat slower speed of manœuvre from which all two-seater aeroplanes are likely to suffer on account of their increased size. The value of the two-seater will depend almost entirely upon the degree to which training in gunnery can be developed. The question of aimed fire from an aeroplane is one of considerable difficulty, and the more rapidly the aeroplane is manœuvred the more difficult does it become.

Gunnery.

Although much experimental and research work was done towards improving the standard of aerial gunnery during the Great War, the conditions of training were such as to make it impossible to provide sufficient training to make the best of things. In the general way, the fixed gun firing straight ahead was as much as a pilot could manage, and comparatively few pilots became even passably expert. In special cases, as undoubtedly in that of the late Captain Ball, V.C., successful use was made of a Lewis Gun fixed to the top plane, mounted so that the elevation could be altered, but comparatively few other pilots copied the example of that highly successful air fighter.

It seems to the writer that further development of aerial gunnery depends entirely on the attitude taken up by the Air Force authorities, and to the time and energy they are prepared to put into the training of our future fighting pilots. If there is the demand, it is certainly possible to arrange for movable guns which can fire through the propeller, or to make fighting aeroplanes in which the propeller is behind the pilot. It is also possible to arrange that the effort of moving the

gun or guns can be provided mechanically, and that all the pilot has to do is to move the sight with the knowledge that the gun will turn with it. Mechanism of this type can be made, but it has little chance of being made unless the demand for it comes through the Royal Air Force itself.

It will probably be said that the suggestion of moving the gun and the aeroplane in different ways at the same time is hopelessly difficult and is scarcely worth attempting. The reply to this is that many other equally difficult things have seemed to be impossible, but gradual improvement in training has so developed the technique of it that what once appeared to be impossible now becomes comparatively easy. Some 200 years ago Sebastian Bach wrote certain music for the violin which nobody could play. Later on there arose some violinists of genius who managed to surmount the technical difficulties and to do what had been believed to be impossible. Gradually the technique of violin playing was developed until at the present day this same music can be played by boys and girls of comparatively tender age and it is no longer looked upon as a mark of anything more than good training to be able to do so. In the same way it is probable that we shall find one or two pilots at least who will be able to move the gun and aeroplane at one and the same time. Directly this has become possible, then a careful study of the technique should enable training to be devised so that any pilot of ordinary ability can be trained to do the same thing.

If the Royal Air Force decide that such skill is necessary, then there is no doubt that it can be obtained and the type of fighting aeroplane may undergo a considerable change. It is probable that we can devise a synchronising gear for a moving gun, but it is rather more likely that we shall devise a new type of aeroplane in which the propeller is not in the field of fire. A suggested design for such an aeroplane is shown in Fig. 3, where it will be seen that a propeller is put behind the pilot so that he obtains an unrestricted field of fire ahead.

Armour.

It is not proposed in this paper to deal with the advantages and disadvantages of armouring aeroplanes. It is sufficient to say that offensive aeroplanes must always be superior in performance to the aeroplanes that it is intended to attack, and the addition of armour will certainly reduce performance. It is more likely that the fighting aeroplane will remain almost or quite unarmoured and will depend upon its ability to dodge rather than upon its power to withstand rifle fire.

Size.

The size of aeroplane which is likely to be used on the air fighter in the future is a matter which cannot be settled easily. Certainly the smaller the aeroplane the quicker is it likely to manœuvre. At the same time, so long as a minimum size is necessary to carry the standard armament that appears necessary, it is always possible that a pilot of abnormal skill will be able, on a small aeroplane carrying little ammunition and perhaps a single gun, to outmanœuvre an aeroplane more heavily armed. The records of the Great War seem to show that the most successful aeroplanes on the whole were not the smallest. All we can say, then, is that the smallest size aeroplane that will carry the armament found by experience to be necessary is the aeroplane that should be used. The useful size appears to the writer to weigh in the neighbourhood of a ton, and taking 8 lbs. to the sq. ft. as the probable loading, this means a machine with about 280 sq. ft. of surface. An aeroplane of this size can be made extremely light to fly, and if the aspect ratio of planes is kept small, sufficient manœuvrability can be obtained to ensure that it is not appreciably slower in this respect than any other aeroplane.

Small aeroplanes are undoubtedly attractive, and there is always likely to be a peace-time tendency to encourage the making of aeroplanes which will not carry sufficient armament to render them really valuable war-time machines.

The horse-power that will be used will probably be the most that can be obtained from a motor weighing about 700 to 750 lbs. complete. What this will be the future will show. The writer thinks that in ten years' time it will be in the neighbourhood of 400, and that this power will be maintained to a height of at least 10,000ft.

The Fighting Aeroplane in the Future.

It is very unsafe to predict the development of aeroplanes. All sorts of new inventions and discoveries will help to improve the type. Looking perhaps ten years ahead, the writer thinks that we may look forward to the development of two separate and distinct types of single-seater fighters—one adapted for attacking enemy aircraft in one long dive and the other more suitable for combined work and "dog fighting." The former type is likely to remain rather similar to that now in use. It will probably be of the conventional tractor type and which should certainly be armed in such a way that the rate of fire will be at least 4,000 rounds per minute, while the ammunition carried is likely to be some 3,000 rounds. The speed of the aeroplane at 20,000ft. would be in the neighbourhood of 160 miles per hour, while diving from that height a speed of 300 miles an hour is likely to be attained. The rate of climb at 20,000ft. should be 1,000ft. per minute. Fuel for $2\frac{1}{2}$ hours at economical speed will probably be sufficient. The duties of this type of aeroplane will be to patrol the skies and to pounce on any unfortunate aeroplane which is trying to carry out reconnaissance, bombing or other duties.

The other type of aeroplane that should be developed is one in which the pilot has a clear field of fire ahead and in which almost everything is sacrificed to rapid manœuvring. The guns should be mounted so that they are moved by some form of servo motor in accord with a sight. The rate of fire in this aeroplane is not quite so important, possibly 2,000 rounds per minute will be sufficient, and the amount of ammunition carried should be the same as in the previous case, namely, 4,000 rounds. The speed of this type is not so important and possibly 150 miles per hour at 10,000ft. will be enough. The climb, however, should be at least 2,000ft. per minute at that height, not with the idea of securing a high ceiling, as this machine will probably operate at comparatively low altitudes, but so as to get the maximum possible manœuvring power at any height. The amount of fuel to be carried is less certain and will probably be adjusted according to the ammunition carried or the performance required. The work of this aeroplane will probably be carried out in squadrons, and their duties will be to attack formations of enemy aircraft and to protect our own reconnaissance and bombing machines to some extent.

Two-Seater Fighters.

Two-seater fighters of the future are harder to forecast. It is not certain that it will pay to keep two-seater fighters solely as fighting machines. It is more likely that this type would be developed as reconnaissance machines capable of fighting, but this will depend upon the system of training adapted by the Royal Air Force. Unless the training is carried out so that the crew have implicit confidence in one another and are accustomed to team-work, this type of aeroplane is doomed to failure. The superior initiative of the single-seater fighter will be the deciding factor. If, however, the pilot knows and trusts his gunner, then improved moral may prove the turning point.

The question of moral enters largely into the problem. The value to an air force of having the recognised best fighting machine is possibly as important as the actual damage which these fighting machines can do. Happily for us the temperament of the men of this country seems to produce a large supply of pilots suited to the work, and so long as designers are able to produce aeroplanes worthy of their skill we have little to fear of losing our supremacy in this respect.

DISCUSSION.

The CHAIRMAN said they had listened to an interesting lecture, the earlier part of which had dwelt on that part of the history of the aeroplane that so many of them had worked in and the latter part on a forecast of the future of the fighting craft. There were many points in this very suggestive paper upon which the audience would have views based on their war experience as designers and fighting flyers, and he hoped that they would give expression to them. A number of gentlemen had sent in their names as intending to speak, but unfortunately the inclement British weather had kept some of them away. He would ask Major Buchanan to open the discussion.

Major BUCHANAN thought the Society was to be congratulated on having induced Major Green to record his experiences and his opinions of what the single-seater of the future ought to be. Air Force officers and designers did not agree very closely as to what the requirements of the future should be, and it was all to the good that men should come forward and put on record definite expressions of opinion so that other people who might think differently, or who might agree, could also record their opinions. The difficulty of single-seater work in the past had been to get a definite impression of what was required. During the war the conditions changed so rapidly that experience with any particular type under any particular conditions was not of long duration. He would like more information on a matter upon which he was not quite clear, viz., manœuvrability. The paper suggested, he believed, that the criterion of manœuvrability was the smallest circle in which an aeroplane could turn. He did not think the author really meant that, although it was one measure of it, because they might have two aeroplanes, one which turned in a larger circle than the other, but if the machine turning in the largest circle had the same angular velocity as the other, then for fighting purposes, at any rate, the other would come down if the latter were quicker in getting into the turn. He believed there were many fighting pilots present, and he hoped they would correct him if he were wrong, but his own opinion was that the criterion of manœuvrability was the speed at which an aeroplane could get into a turn, make the turn, and come out of it again. Another point he would like to raise was the question of the moment of inertia. He thought the author was quite right when he said that putting a pilot behind the main planes increased the moment of inertia and therefore was inclined to make it more difficult to manœuvre the machine. In the fore and aft direction this increase of the moment of inertia was of very little importance, but in other directions it was rather important, because it did affect the speed of getting into a turn. Another point was the vexed question of the amount of stability a single-seater required in the future. That question was discussed in most Air Force messes, but he did not think anyone had come to a very definite conclusion about it. The general conclusion seemed to be, from discussion with most officers of the Air Force, that a slight degree of positive stability was required. If Major Green divided the single-seater of the future into two types, viz., the high altitude and rush type on the one hand, the dog-fight type on the other, the stability required would vary with the particular type. He would very much like Major Green to give them the benefit of his experience on that subject because it was rather important and was one which was very much discussed. With regard to Major Green's final type of single-seater, being a conservative person he himself was rather in doubt. He should prefer to wait and see before saying very much about it. Major Green had emphasised the point that it was possible to train people to do things which were previously thought to be impossible. That was quite true, and Major Green had applied it to the training of the gunner, but it must not be forgotten that the same process of training would also govern pilots and enable them to manœuvre aeroplanes very much more rapidly than was considered possible at present, and it was possible that we might arrive at the same result by two different systems of intensive training.

Wing-Commander BOWEN, called on by the Chairman, said he had nothing to say.

The CHAIRMAN: There is the instrument side of the question.

Wing-Commander BOWEN said that on points like that they must remember that they had to cater for short service officers and it was absolutely essential that anything which was produced, however marvellous the results it gave might be, must be of such a nature that it could be manipulated by comparatively untrained personnel. It must be simple to use, and it must be what they called "fool-proof"; it was not a bit of good introducing stuff that was going to be complicated to use. In regard to the general position of the future, the policy seemed to be to produce a machine which would fulfil many functions, and do three or four different jobs in the same day. It might go out on ranging and spotting in the morning, long reconnaissance in the afternoon, and be called upon, perhaps, to carry mails in the evening, but whether the specialised machine would be a practical proposition for the future Air Force, with the financial limitations, he did not know. He was rather inclined to doubt it. In any case, they must always come back to the point that they had to produce something that must be used by a comparatively untrained personnel, otherwise the instant war broke out and they had to enlarge the Force, the whole thing would go to pieces if they had complicated stuff.

The CHAIRMAN: Now I want a pilot.

Squadron-Leader HOBART said he would like to speak about the two types which Major Green had discussed, viz., the one rather taking after the S.E.5 type, which would probably be used purely to dive on an enemy—the hit or miss type—and then climb again and dive again or give up the job and go straight home, as so many of the Huns did; and the other type, the dog-fighting machine, which on account of its superior manœuvrability would keep on the same level and win simply by manœuvrability. Personally he was rather doubtful whether manœuvrability alone was going to give the right machine for an offensive action. Manœuvrability very often meant that the machine was very excellent for defence but not for an offensive action. He thought that if the two types of machine were put up against each other to see which would win, the superior climbing one would win. It was not simply a question of shooting past the enemy, but it was a question of diving on to an enemy and climbing up again with the velocity gained in the dive. He knew of a case at the front in which one of our Sopwith Pups, with excellent manœuvrability, was dived down on by three Huns, one after the other, getting down to the level of the top of the Sopwith and climbing up again with the velocity gained in the dive. That was done in turn by each of the three Hun machines, so that there was always one machine diving, and they never gave the Sopwith a chance of getting out of a turn. In fact, the pilot had to keep on turning until the Huns got tired of it. It was a very nice type of machine, with manœuvrability like that, but it did not lend itself to a satisfactory offensive action, unless they had the climb as well. It was a very difficult point to decide how much manœuvrability one could sacrifice in order to get the climb in place of it. He believed that a lot of pilots would choose the machine with the superior climb and sacrifice manœuvrability, because an offensive action was based on climb provided manœuvrability was somewhere within ordinary limits.

Personally he was doubtful about a movable gun because he was an extremely bad shot himself, and he believed that the average pilot, even after several years of the war, would not do good shooting with a gun of that description. With two guns firing at the rate of from 400 to 600 per minute, it was astounding what the pilots missed. They often got right on to the tail of their objective and went on firing, and simply nothing happened at all, and one did not know where the shots were going. Towards the end of the war, when destruction of the enemy increased a great deal, he understood that it was

due entirely to the speeding up of the firing to 2,000 per minute, and he believed that was the sole cause of war pilots coming into the killing class where previously they were in the missing class. Personally he thought that if they could have two fixed guns and have manoeuvrable machines and increase the number of rounds, and even increase the number of guns, so that they could have still more rounds in the air at the same time—he meant on a small machine, that would be the most destructive machine. He was not against the moving gun, but felt that it was only suitable for highly trained pilots. He thought it would be worth while having a few made to be tried by thoroughly experienced pilots. His point was that he felt that the average pilot would do better with a fixed gun.

Captain PAYN said the question of manoeuvrability interested him particularly because he had, unfortunately, had a fairly large experience with recent machines. He shared Wing-Commander Bowen's opinion, as far as he was able to judge, on the question of moment of inertia. It did not seem to enter into it very much, but he thought the question of lateral control was a very pronounced one and limited a machine very much, assuming there was adequate rudder and elevator control. Rudder control they must have to cope with the manoeuvrability necessary to effect slow landing in awkward circumstances, but at top speed or thereabouts, in manoeuvring after a dive, he felt it was essential that lateral control should be good, and by good he meant that they should get a certain roll, and a machine which had that to a pronounced degree was essentially the more manoeuvrable. As to the question of the use of the elevators, it would appear that a limit was reached purely by strength. Assuming that they had sufficient horse-power to give the necessary speed and rate of climb, which followed with it, the limit then appeared to be how far the pilot dared approach the maximum incidence at that particular speed, so that the machine did not break in the air. He would very much like to hear Major Green's views on that point. He was very interested to hear Major Green's prophecy for the coming years, but if development was to be so rapid would it be worth while making machines of such durability as he had suggested?

He shared the previous speaker's opinion that fixed guns and a manoeuvrable machine giving a sufficiently large and intense zone of fire was the best. The general aiming should be done by the aeroplane, and accurate aiming would not be so necessary.

The CHAIRMAN said that if they were making a mass attack and had a number of ships against a lesser number of ships, the strength of the fire was increased in proportion to the square of the number. Two aeroplanes were four times as strong as one, and proportionately, provided they could attack. If they had 16 aeroplanes and could only fire at the target by going for it, they would meet, whereas if they could move their guns they could fire at the same time without meeting. They did not want them to meet.

Captain PAYN said he was only considering the single-seater type. It might be a better proposition to have the movable gun on a two or three-seater type of machine.

The CHAIRMAN said they might have single-seaters in mass formation, and if the enemy had movable guns, that might assist them to win as against single-seater machines with fixed guns.

Captain PAYN said that perhaps he had not given a very good answer, but he had not had a very great experience as a fighting pilot. It might be as the Chairman had said, but if the enemy's machines had a superior performance, the enemy would not worry after a very short time.

The CHAIRMAN said he was glad to have Captain Payn's answer, which he regarded as very valuable.

Captain PAYN, continuing, said that he also shared Squadron-Leader Hobart's view as to manoeuvrability. One machine he had flown was extremely

good. It was fairly lightly loaded and they had great faith in its strength. They were able to pull it round to the limit of its capacity, until the wings were stalled. It was a D.H.2, and the guns were movably mounted. It was a wonderful machine in its day.

Wing-Commander CAVE-BROWNE-CAVE thought it was particularly valuable that Major Green should have come forward with a paper on the characteristics of fighting machines because it was a subject in which interest had to be artificially stimulated. Many people were interested in the characteristics of commercial machines, but it was, even in the Service, very difficult to get the characteristics of fighting machines even discussed. To make the discourse complete, there should be something dealing with the type of machine which would be used for fighting under naval conditions, and he did not know whether the Council would be able to get a companion paper on that question. He had been very interested in the expressions of opinion as to the demerits of moments of inertia. The Fire Prevention Committee were, he believed, pretty well satisfied that if it were possible to put petrol tanks on the wings of the machines some distance out, the probability of the machine being destroyed by fire when flying or in a crash would be very much reduced. It was almost certain that the tanks on the wings would, if ignited, blow out, and in any case the burning of the structure of the machine would be very much more gradual. He believed the accepted opinion at present was that an increase of the moment of inertia, with these tanks far out, would be a very serious handicap to the machine in fighting. The author had explained that what limited the manœuvrability of the machine at present was its strength, and that if they increased the moment of inertia they would not render more drastic manœuvres impossible. He believed that was so in the case of manœuvres in pitch, but he did not think it was the case in regard to manœuvres in roll or yaw, and he would be glad to have his opinion on that point. A totally different point was the question of training pilots. Although he had had absolutely no experience whatever as a fighting pilot he was inclined to agree with Major Green, rather than the fighting pilots who had spoken; for this reason, that the things which could be effected by training over a period of years, as distinct from the very intensive training which was all that was possible during the war, were so remarkable that he could not help feeling that the possible development of the human skill must necessarily be very great. The trouble was this; how were they going to carry out that training? He was at the Isle of Grain trying to devise a scheme of competing with the gunnery instruction school at Eastchurch in aerial fighting, but it was an extremely difficult thing to do. They were playing the stations around them at the various games, where the method of competition had been more or less reduced to a definite system, but how were they going to carry out the most important form of competition, viz., training in aerial fighting? The camera guns went a long way, but they would have to get something very much more satisfactory before they could reckon that the laws of aerial mock fighting were as satisfactory and realistic as the laws of boxing or of fencing. Until they could get a system of training which fairly satisfactorily produced the conditions of actual fighting, they missed two very valuable points. One was, they did not train their pilots in actual fighting, and when action came they felt strange and new to it. The other was that they could not effectively work out the merits of alternative types of machine because the expressions of opinions of pilots were not sufficiently certain or reliable even at this short period after the war for the fighting machines of the service to be developed solely by such expressions of opinion. There must be something a little bit more practical than pilots' experiences during the war using different types of machines. There were very few problems of greater importance to the development of fighting aircraft than the evolution of some artificial method of reproducing the actual process of aerial fighting. The question of the movable gun was primarily one of training the pilot. A mental development such as that which evolved the modern gunnery

officer from Nelson's master gunner should render possible in aerial fighting things much more complex than the moving gun.

Lieutenant-Colonel HECKSTALL SMITH, referring to the statement in the paper that Bach had written music which could not be played, said one could hardly ask an aeroplane designer to design a machine so that it required an infinite amount of technical skill to fly and would take years to learn. The whole crux of the design of the fighting aeroplane depended on the number of available pilots who were going through their training, and he noticed that in the lecture before the Royal Society of Arts given a short time ago by Sir Hugh Trenchard, he definitely stated that it was not any use training pilots in large numbers at the present time because they would be too old to be of any use in the next war. That was a definite statement and was very interesting because it meant to say that unless they could decide definitely on training for a number of years, they could not say how skilled the pilot was going to be, and therefore how delicate the fighting machine, which probably could be improved. That was what the designer had to make his design on, and unless he had some measure of knowledge of the skill to which pilots were going to be brought in numbers, it was no use going on designing machines to any great degree of delicacy such as Major Green had suggested. Experience was required, and Major Green had rightly pointed out how essential it was to have co-operation between the designers and the heads of the Air Force who were going to train the pilots, so that the machine of the future might be designed for the pilots of the future.

The CHAIRMAN said he would now call on Major Green to reply to the discussion as he was anxious not to form a precedent for exceeding the time or encroaching on the dinner hour. Any others who wished to contribute to the discussion were invited to send in their communications to the Secretary.

Major GREEN said that a number of points raised in the discussion were common to several speakers and that he would therefore answer some of them collectively. With regard to manœuvrability he thought he had made it clear that manœuvrability and climb were very much the same thing. He agreed with those speakers, therefore, who emphasised the importance of climb. He thought that pilots were a little apt to mix up manœuvrability and stability. An unstable machine unquestionably manœuvred itself extremely fast on certain occasions, and people were apt to think that a stable machine could not be manœuvred as fast as an unstable machine because it generally felt steadier. Personally, he did not think that a small margin of positive stability hindered manœuvrability, and at the same time he was definitely in favour of stability both for comfort and safety of flying, and also because it made a much steadier gun platform.

A machine which was intended to attack by diving should certainly be stable over its whole range of speed, while the highly manœuvrable machine was probably good enough if it were stable over its ordinary flying range. Stability did not involve any appreciable amount of weight. With regard to manœuvrability he agreed that turning was not the only point. He had taken this as an example and did not profess to discuss the question of manœuvrability to the full, as it would have made a long paper in itself. Speed of getting into the turn was very possibly the deciding factor, but so long as the aspect ratio of the machine was kept fairly small, he believed that the remarks he had made were correct.

Major Buchanan had said that the fore and aft moment of inertia affected rudder control. The speaker agreed that it did, and he had always failed to see why aeroplane designers used such small rudders. The amount of weight for a few extra square feet was small, and on machines of this size it was easy to balance the rudder to any required amount. He was convinced that rudders, on the whole, were made too small.

Wing-Commander Bowen, when asked his opinion, said he preferred to wait

and see. That was a safe thing to do; perhaps the speaker himself would have been wiser to have done it. The point that he had been trying to make was that the machines which the designer produced depended largely on the requirements of the R.A.F., and that the requirements of the R.A.F. depended on the sort of aeroplanes that they actually obtained. In this way we reached a deadlock, and it was necessary to have some sort of discussion periodically when both the R.A.F. and the designer could suggest seemingly impossible things for the other to do. In the general way the suggestions for difficult things came from the R.A.F., and it seemed only fair that the designers should suggest difficult things for the R.A.F. to do, such as the moving of the gun and the aeroplane at the same time. The speaker had suggested that the R.A.F. ought to use intensive training to enable pilots to handle aeroplanes in a way that was not now done. It was not suggested that aeroplanes suitable for this work should be ordered in large quantities. The suggestion was that it was worth while seeing whether training on these lines could not be developed, and the difficulty was not in carrying out the training so much as in finding out how to do it. If this was not done he did not believe it was possible to improve the fighting machine as otherwise might be done.

Wing-Commander Bowen had spoken of complication. The speaker agreed that complication should be avoided as far as possible, but that complication in aeronautics was inevitable. An aircraft engine was immensely complicated, and the sort of complication that had been suggested in the paper would be quite small compared with it. It was, after all, only a matter of degree.

Wing-Commander Bowen had also said that we must not have specialised machines. If we could afford to say that for a number of years we were going to have no more big wars, and he sincerely hoped that we should not, and if we are prepared to shape our policy on these lines, then many of the things he had said might be modified. It was necessary to be able to get ready in case of war as quickly as possible, and although we might not order specialised machines, we ought at least to keep them alive. It was a difficult problem, but if we could only find out how to do it we should have advanced a long way.

The third speaker said that manœuvring and climbing were bound up together, and in this he quite agreed. He also agreed that too many bullets went astray and that was the reason why he wanted to get a machine which would fire the maximum number of bullets in a given time. It was not suggested that we should neglect to train people with the fixed gun; in fact, all the ordinary training must be with the fixed gun, and he hoped that this would be carried out so that there would be as few missed shots as possible.

The speaker agreed with Captain Payn that lateral control is probably the biggest part of manœuvrability; it did not affect the question seriously whether the aeroplane was stable or unstable, and he did not think that quick lateral control demanded greater strength. The limit of strength came only when manœuvring in the fore and aft direction; quick banking did not affect the question seriously. Captain Payn had asked why we needed durable machines if everything was to be changed rapidly. The speaker had not suggested that aeroplanes would change rapidly. He had only pointed out the sort of thing that might happen if fighting machines were kept alive. We must always keep ahead with possible development in view of the possibility of war. Captain Payn had also said that a two or three-seater would be better because then they have a movable gun. This seemed to be begging the question. If a single-seater could be used with a movable gun it would be better because it costs less money and involves fewer pilots. It seemed probable that it was better to train one pilot well than a pilot and observer less well.

He was glad that Wing-Commander Cave-Browne-Cave had supported his view that the fighting aeroplane had got to be kept alive. There was always likely

to be a peace-time tendency to return to smaller aeroplanes although their use was not supported by experience during the Great War. With regard to petrol tank position, he did not know the exact importance of moment of inertia sideways. It had some influence, and he believed it could be calculated directly. It probably had the greatest influence at the beginning of the turn and afterwards very little.

Lieut.-Col. Heckstall Smith had said that the paper suggested using aeroplanes that could only be flown after years of training. This was hardly correct. The speaker had asked for an aeroplane that could not be fought to its best advantage except after long practice, but there was no reason why it could not be flown as easily as any other aeroplane.

Major BARLOW (*communicated*): There are two points I should like to bring forward bearing on this excellent paper by Major Green as a result of my experience at Martlesham Heath.

In discussing the all-important question of view, Major Green states that in his opinion the cutting away of the centre section top plane is bad for aerodynamic reasons. This is not borne out by actual tests. A Camel with the centre section partially cut out to give a better view has been found to have the same aerodynamic properties with, if anything, a slightly better performance. In confirmation of this, I should like also to refer to two aeroplanes designed by the Westland Aircraft Company, namely, the little "Wagtail" single-seater scout and the "Weasel" two-seater fighter. Both these have excellent view in the top hemisphere with cut-away top plane centre section, and I think I am quite at liberty to say both aeroplanes in their class and type can hold their own in performance and manoeuvrability as fighting aircraft.

The second point is manoeuvrability. In this I strongly support the remarks of Captain Payn. Undoubtedly lateral control is one of the deciding factors, and this is borne out by the extraordinary manoeuvrability of an aircraft which all pilots will agree had a marvellous aileron control, *i.e.*, light, very quick and effective. I refer to the Fokker biplane. This aircraft had not a remarkable high rate of climb or speed, but the combination of wing section with its high efficiency controls have more than counteracted for this small deficiency in performance.

I should like to have heard Major Green's technical opinion on the possibilities of monoplane scouts with cantilever construction coming to the front again. However, the points raised in the paper should do much to help on this question of fighting aeroplane design, which I can assure the lecturer is constantly being discussed by the majority of pilots and technical officers of the R.A.F., certainly at English experimental stations.

ANSWER TO MAJOR BARLOW'S REMARKS COMMUNICATED IN WRITING.

Major Barlow states that cutting a hole in the top plane does not affect performance. This I find difficult to believe unless there was one peculiar reason connected with the aeroplane, such as the excessive interference between the top plane and the body. On all the tests that I have been able to carry out myself there has been a distinct loss of performance.

I quite agree with Major Barlow about manoeuvrability. Good aileron control is certainly one of the deciding factors, but it certainly ought to be combined with a rudder of sufficient size.

With regard to monoplane scouts, I do not think that they are likely to have much future. It seems to me that a monoplane must have a bigger span than a biplane; hence the all-important lateral control is likely to be slower.

THE FAN PROPELLER AND BLADE INTERFERENCE.

BY M. A. S. RIACH, F.R.A.E.S., ASSOC.INST.N.A.

For some time it has been recognised that the aerodynamical theory of the screw propeller, as at present presented, leaves considerable room for improvement. The leading specialists in this branch of aerodynamics, such as Mr. Fage, Mr. McKinnon-Wood and Dr. Watts, have given recognition to the all-important fact that a velocity of inflow can only be produced by the mutual interfering action of the propeller blades upon each other. Dr. H. C. Watts was, I believe, the first person to point this out clearly, and to show that the hitherto accepted theories of inflow rested upon a highly empirical basis. By "velocity of inflow" is meant the *additional* velocity required to modify the method of propeller analysis, known as the blade element theory, originally enunciated by S. Drzewiecki in 1892. The accepted and standard inflow theory of the airscrew, as, for example, given in Professor L. Bairstow's "Applied Aerodynamics," rests upon the empirical assumption that the ratio (velocity of inflow)/(velocity of impressed slip) is a constant for all propellers and for all radii along the propeller blade length. The numerical value of this ratio it has been left to experimental research to determine, but fundamentally it is nothing more nor less than an empirical factor of ignorance to be justified only by the sparcity of time and the pressure of work during the war period. It is time that a more rational, because more fundamental, theory was evolved. In attempting to produce such a theory I have started out with two basic postulates:—

- (1) The blade element theory of Drzewiecki is correct, to a sufficient degree of approximation, *if blade interference be supposed to be non-existent.*
- (2) The physical action of an airscrew may be represented, to a good degree of approximate accuracy, by incorporating with (1) the effects of blade interference.

I consider here only the special case of a propeller working without axial advance in a fluid, *i.e.*, what has been called the "static" case. The general case of propeller action is of necessity more difficult, and it is thought that the present paper will have achieved its object if it suggests a line of inquiry which may prove fruitful in the general case as judged by the results given by the theory in the static case of screw action.

It is well known that if any symmetrical body be moving uniformly through air at rest, some air will be pushed along in front of the body and continue to be pushed along so long as the action continues. Conversely, if air be moving past a body at rest, some of the air in the neighbourhood of the body will be slowed up and this will continue so long as the action lasts. In both cases the action upon the air, in the neighbourhood of the body, gives rise to a force which is known as the resistance of the body to the motion. If U be the velocity of the body relatively to the air a long way in front of it, and Σ be the velocity which the body impresses upon the air, then the change in energy per second in the relative air stream is $\frac{1}{2}$ (mass of air per second affected) $[U^2 - (U - \Sigma)^2]$, the resistance force is (mass of air per second affected) Σ , and the work done per second by the resistance force upon the air is (resistance) V , where V is the relative velocity between the body and the air *at* the body. Then if the work done by the body

upon the air is equal to the change in energy in the relative air stream, we have simply:—

$$\Sigma V = \frac{1}{2} [U^2 - (U - \Sigma)^2]$$

i.e., $V = U - \Sigma/2$, which gives the relative velocity *at* the body. Now the above is a very elementary conception and in practice the conditions are far more highly complex. It is intended by way of illustration only.

Consider now a more difficult case, the case of an aerofoil moving uniformly through air at rest or, conversely, air moving uniformly past an aerofoil at rest in it. The same general type of thing occurs here (Fig. 1).

I call γ the gliding angle of the aerofoil, so that: $\tan \gamma = \text{drag/lift}$. Then it is seen that the component velocities, normal and tangential to the direction of the resultant force upon the aerofoil, are $U \cos \gamma$ and $U \sin \gamma$. We may, by way of illustration, consider the component velocity $U \sin \gamma$ to be analogous to the free wind velocity of the case already considered and then we may expect this velocity to be slowed up as it passes the aerofoil, the other component velocity $U \cos \gamma$ remaining unchanged in value.

The aerofoil, as it moves, pushes some air along with it, but principally downwards. Call this impressed velocity Σ , and let part of it be present *at* the aerofoil and call this part $\sigma \Sigma$. Then, if we pursued the same reasoning as before, we should find the value of σ to be one-half. At present we shall leave it indeterminate in value. Then the relative *component* velocity *at* the aerofoil is not $U \sin \gamma$, but $[U \sin \gamma - \sigma \Sigma]$ (Fig. 2).

Hence the resultant velocity *at* the aerofoil is now seen to be inclined to the free wind direction at an angle of ξ and to be equal to

$$W = \sqrt{U^2 \cos^2 \gamma + (U \sin \gamma - \sigma \Sigma)^2}.$$

Notice that this resultant velocity W at the aerofoil may be constructed either by the velocities $U \cos \gamma$ and $(U \sin \gamma - \sigma \Sigma)$, or by the velocities U and $\sigma \Sigma$. The component velocity $U \sin \gamma$ is slowed up as it passes the aerofoil by the amount of the impressed velocity $\sigma \Sigma$ so that the component relative velocity *at* the aerofoil is $(U \sin \gamma - \sigma \Sigma)$.

Call the angle of chord incidence to the free wind direction α_r . Now I want to consider a hypothetical case in which it is to be supposed that a quantity of uniformly deflected air moves past the aerofoil in relative motion and with the relative velocity W . Let the depth of this layer of air be Δ , and let the chord width of the aerofoil element over which this air is supposed to flow in a two-dimensional motion be b . Call $b/\Delta = \delta$. Then I propose to show that this ratio δ may be regarded tentatively as a general constant.* Consider an element of aerofoil surface of span dx . Then the volume of air flowing over this element per second will be $\Delta dx W$, its mass per second will be $\rho \Delta dx W$, and the resultant force upon the aerofoil element will then be $\rho \Delta dx W \Sigma$. Now write down the aerodynamical equation for the resultant force. It is

$$\sqrt{k_y^2 + k_x^2} \rho b dx U^2,$$

where k_y and k_x are the coefficients of lift and drag respectively and ρ is the mass/density of the air. Then

$$\rho \Delta dx W \Sigma = \sqrt{(k_y^2 + k_x^2)} \rho b dx U^2$$

$$\text{i.e., } W \Sigma = \sqrt{(k_y^2 + k_x^2)} \delta U^2,$$

which defines δ . Also

$$\tan \xi = (\sigma \Sigma \cos \gamma) / (U - \sigma \Sigma \sin \gamma) \quad (\text{see Fig. 2}).$$

Hence

$$\sigma \Sigma \cos \gamma = (U \tan \xi) / (1 + \tan \gamma \tan \xi),$$

and

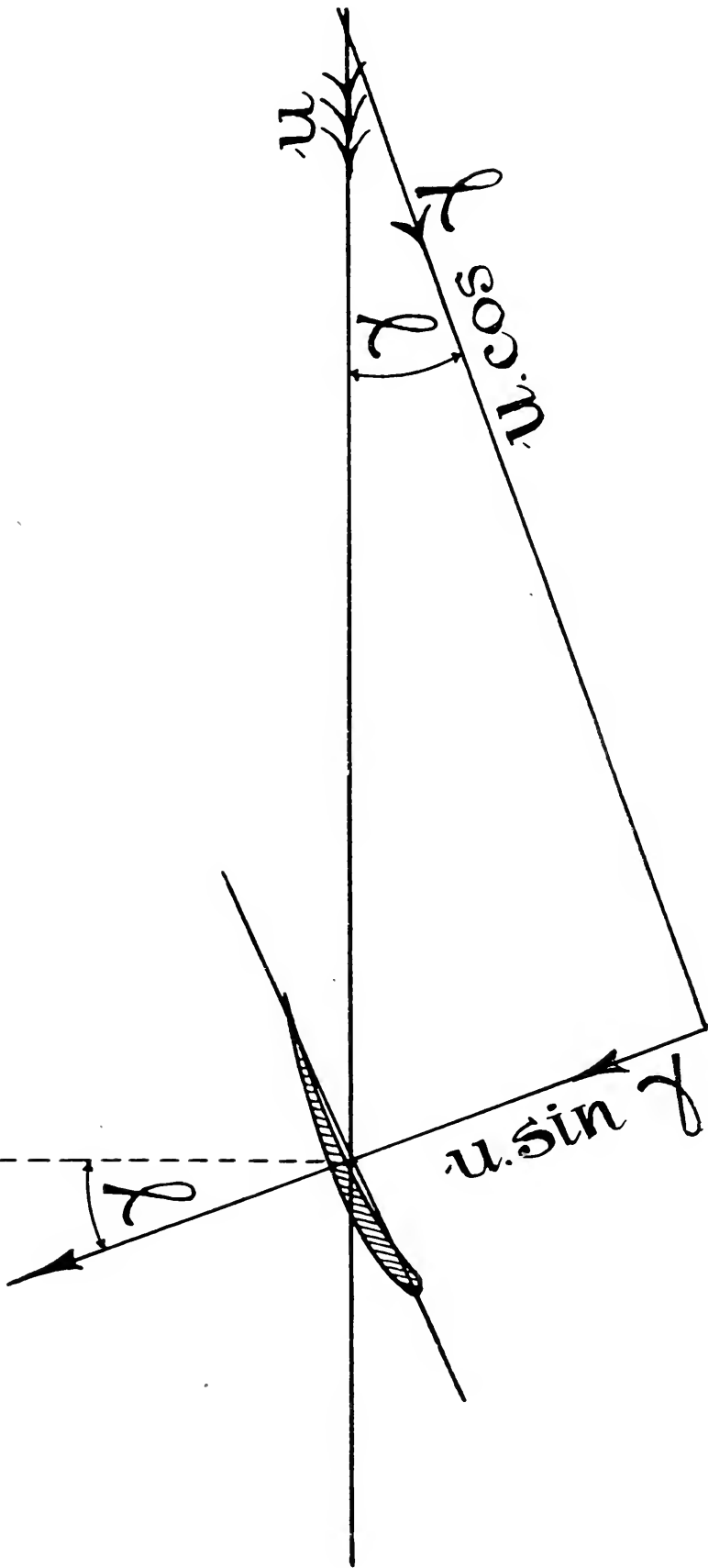
$$\therefore (W/\sigma) (U \tan \xi) / (1 + \tan \gamma \tan \xi) = k_y \delta U^2,$$

$$\therefore \sqrt{(k_y^2 + k_x^2)} = k_y \sec \gamma.$$

* It will be seen later that this is not strictly necessary.

FIG. 1

RESULTANT FORCE



Further,

$$W = U / \cos \xi (1 + \tan \gamma \tan \xi) \quad (\text{see Fig. 2}).$$

And

$$\therefore (1/\sigma)/(U^2 \tan \xi \sec \xi)/(1 + \tan \gamma \tan \xi)^2 = k_y \delta U^2$$

$$\text{i.e., } (\tan \xi \sec \xi)/(1 + \tan \gamma \tan \xi)^2 = \sigma k_y \delta$$

or alternatively since $\tan \gamma = k_x/k_y$;

$$(\tan \xi \sec \xi k_y)/(k_y + k_x \tan \xi)^2 = \sigma \delta.$$

Now for the angles with which we shall have to deal, ξ is always a small angle so that we can write approximately:—

$$(\pi/180) \xi k_y/[k_y + k_x (\pi/180) \xi]^2 = \sigma \delta$$

Solving the quadratic for ξ we get to the same degree of approximation:—

$$\xi = k_y \delta \sigma (180/\pi)/(1 - 2k_x \sigma \delta)$$

Now it is known, from experiments on “downwash” angles, that the angle of downwash varies as the lift coefficient almost exactly, *i.e.*, that $\xi = \Omega k_y$, where Ω is a constant for the aerofoil shape. Hence, $\Omega = (180/\pi) \delta \sigma/(1 - 2\delta \sigma k_x)$, and $(\sigma \delta k_x)$ is small compared to unity, so that we may conclude that $\sigma \delta$ is a constant† and, if σ be a general constant, then δ is a constant and tentatively may be assumed to be approximately a general constant.

This point, as already mentioned, I wished to demonstrate. The value of Ω has been found by experiment to be about 20 in round numbers, so that we can conclude tentatively that a value of $\sigma \delta = \pi/9$ is of the right order. Note in passing that, δ being a ratio and the quotient of two linear quantities, its value can change only through change of the angle of incidence if it changes at all—change of chord width for example cannot affect its value because the type of flow round two geometrically similar aerofoils of different size is the same for equal incidence angles, except for small [*vl*] effects which can presumably be ignored at the high speeds encountered in propeller action.

Hence, by substitution, we get to the same degree of approximation the value of Σ given by

$$\Sigma = \{ U \delta \sqrt{(k_y^2 + k_x^2)} \} / (1 - \sigma \delta k_x);$$

so that the total impressed velocity Σ is seen to vary as the free wind velocity and as the lift coefficient for most angles of incidence approximately.

Application to Propeller Theory.

To successfully study the mutual interfering action of the propeller blades upon each other it is necessary to consider them as forming an infinite series of equal members equally spaced apart and to consider the conditions at any member of the series which is far removed from the first member. We study here the cascade series corresponding to any one element of a blade of course. We make the assumption that the conditions at the *r*th member of the series become “steady” as *r* is increased indefinitely, and by this definition of “steady” we mean that the conditions *at* and *after* the *r*th member are all *identical*. We do not, however, imply that the air flow is uniform round the circumference of any annulus in the screw disc, it is probably different at the blades to anywhere else in the annulus, but we assume that it is the same at any one blade as at any other blade (at equal radii of course). Such non-uniformity in the airflow round any annular circumference gives rise to the familiar “gustiness” associated with all propeller action. Consider Fig. 3, which represents a cascade series of equal and equally spaced aerofoil elements.

By our definition of a “steady” state and by our assumption that such a state exists *at* and *after* the *r*th member of the above series, we know that the inflow velocities at all the members of the series, *at* and *after* the *r*th member,

† This is the important deduction.

are *identical*. These inflow velocities are produced by the action of the $(r-1)$ members of the series, from and including the $(r-1)$ th member up to the first member of the series. They are the "legacies" of the *impressed* velocities produced by these $(r-1)$ aerofoils. Now since r is a very large number, it is not to be expected that the action of the *first* member of the series will have any *appreciable* effect upon the r th member. If we consider the aerofoils above to be moving with uniform speed C , from left to right through air at rest, it is evident that by the time the r th member has reached the position aa' the impressed velocity produced by the first member will have practically died out and so have no appreciable action (in producing a speed of inflow) upon the r th member. The same thing applies to the second, third, fourth, etc., members of the series. But when we get close enough to the r th member the "neighbouring" members *do* have an appreciable effect upon the r th member in producing a speed of inflow, *i.e.*, the $(r-1)$ th, $(r-2)$ th, etc., members have such an appreciable effect. So that what we have virtually to try and do is to *sum* a series having an infinite number of continuously decreasing terms. How are we to effect this without knowing the series to be summed? I suggest the following process as being extremely simple and having a rational basis. To begin with, the sum to infinity of the series is finite, for if not we should have an infinite speed of inflow which is absurd. Hence, we may define a number q (not necessarily integral) which shall represent the "mean" value corresponding to the sum to infinity. The definition of q is:—

$$q = \frac{\text{speed of inflow at } r\text{th member}}{\sigma \text{ (impressed velocity of } r\text{th member)}}$$

That is, if

Σ_r = impressed velocity of r th member,

and

$\sigma \Sigma_r$ = the proportion of this velocity *at* the r th member,

and if

Σ_s = speed of inflow at r th member,

then q is defined by

$$q = \Sigma_s / \sigma \Sigma_r, \text{ i.e., } \Sigma_s / \Sigma_r = \sigma q = \text{inflow/slip ratio.}$$

In other words, what number multiplied by the impressed velocity *at* the r th member will represent the sum to infinity of *all* of the impressed velocities *at* all the members from the $(r-1)$ th up to the first inclusive? The answer is q , which is thus defined—

Consider the $(r+q)$ th term.

Since the times taken for the $(r+q)$ th term to move into the positions initially occupied by the $(r+q-1)$ th, $(r+q-2)$ th, . . . r th terms are *small*, provided q is small compared to r , the velocities impressed by the r th, $(r+1)$ th, . . . $(r+q-1)$ th terms will not be sensibly different in value to the impressed velocities *at* these terms by the time the $(r+q)$ th term has moved over all the positions initially occupied by these terms. This is only another way of looking at the *definition* of q . Now obviously the value to be assigned to q is not necessarily integral and will in general depend upon the value of the ratio $2\pi x/Nb$, where x is the blade radius, N the number of blades, $2\pi x/N$ the "spacing" or distance apart of the members of the cascade series, and b the chord width of each member. I now introduce a convention regarding q , for the sake of simplicity only and as a first tentative estimate as to its probable value which may later be discarded if required without interfering with the general theory developed here. q is defined as the number of equivalent members of the series which may be looked upon as producing the inflow speed at the final member next to them (to the left, Fig. 3). Hence, consider Fig. 4.

FIG.3

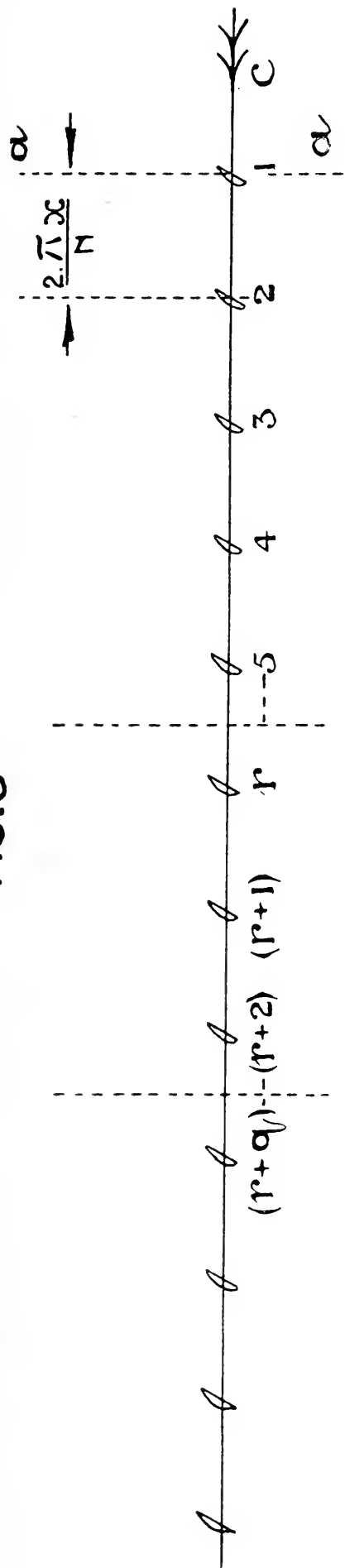
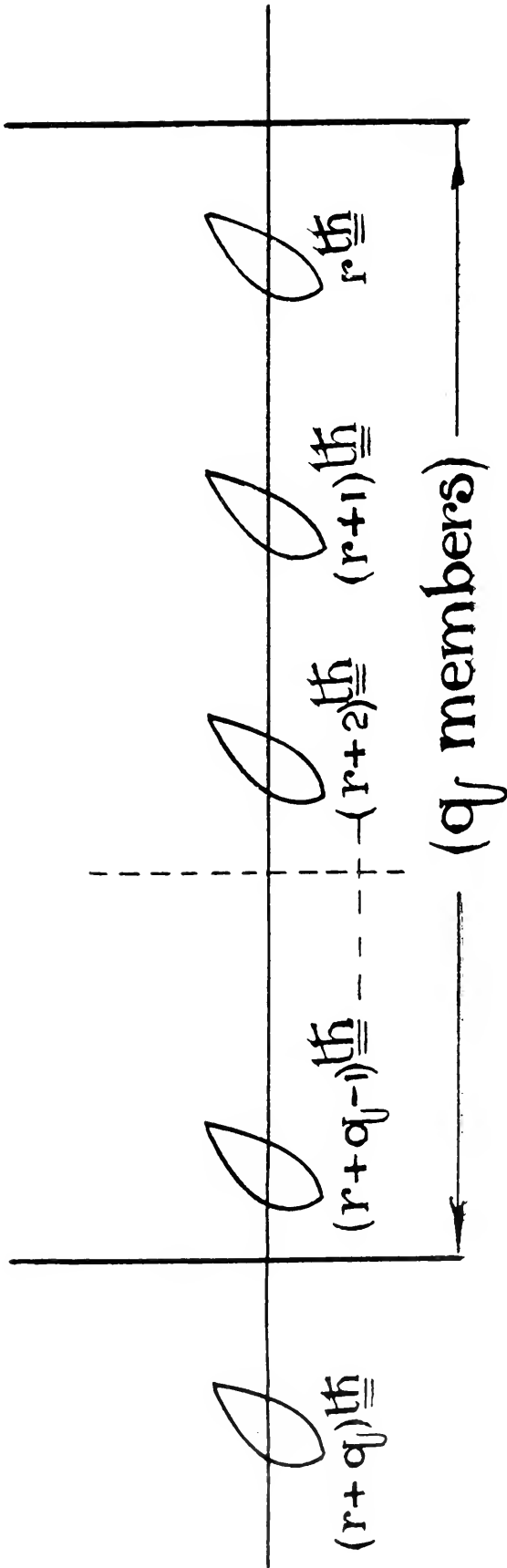


FIG.4



Suppose that we crowd in some more members between the r th and the $(r + q - 1)$ th members, so that the new arrangement of *all* the members (new and old) is still an equally spaced arrangement and all the members are identical. Then, by my convention, I suppose that the *effective* number of members which now affect the $(r + q)$ th member is simply equal to the *total* of the members from r to $(r + q - 1)$, i.e., the sum of the old and new members. And similarly, if we thin out the original arrangement and decrease the total number of members from r to $(r + q - 1)$. Then the total distance from r to $(r + q - 1)$ being $2\pi xq/N = 2\pi xq/Nb$, I suppose by this convention that $2\pi xq/N$ is always of the same value so long as the value of b remains the same. Now evidently if we increase b we get the same effect as by crowding in more members, for then the "spacing" chord width ratio becomes smaller in the same way as by increasing the number of members. Hence, if we are to include the chord width b in our convention for q we must make $2\pi xq/Nb = \text{constant}$. This is what we do and this then constitutes the convention regarding the value of q . Hence,

$$q = Nb (\text{constant}) / 2\pi x = k (Nb/x).$$

Hence now :—

$$\text{Ratio (inflow speed)/(impressed slip speed)} = \sigma q = \sigma k (Nb/x).$$

Then for most general designs of propeller blade shapes this ratio decreases as the radius increases and vice-versa, becoming infinite in value at the propeller boss. The type of curve of variation is very similar to that found experimentally by McKinnon Wood at the R.A.E. in his cascade experiments. The theory is seen to be in good agreement with experiment.

Now consider the conditions at the $(r + q)$ th aerofoil (Fig. 5) where the flow is "steady."

Let the angle of the aerofoil element to the horizontal (i.e., the plane of rotation of the propeller) be α . Then the inflow velocity Σ_s makes the *real* angle of incidence of the aerofoil α_r . C is the velocity of the element due to its rotation (the circumferential velocity) and is the same as the velocity C of Fig. 3. U is the free wind velocity of the aerofoil. W is the relative velocity *at* the aerofoil. γ is the gliding angle of the aerofoil at an incidence of α_r . The velocities $\sigma\Sigma_r$ and Σ_s lie *at the same angle* because the motion is "steady," and Σ_s is the sum of a number of equal $\sigma\Sigma_r$'s.

We can now find the value of α_r , the real angle of incidence of the aerofoil element. From the geometry of Fig. 5 we have:—

$$\sin (\alpha - \alpha_r) = \{ \Sigma_s \cos (\gamma + \alpha - \alpha_r) \} / U$$

But $\Sigma_s = \sigma q \Sigma_r$, and Σ_r is the same as the Σ of the simple aerofoil considered at the beginning of this paper. Hence:—

$$\Sigma_r = \{ U \delta \sqrt{(k_y^2 + k_x^2)} \} / (1 - \sigma \delta k_x) = (U \delta k_y \sec \gamma) / (1 - \sigma \delta k_x)$$

and

$$\therefore \sin (\alpha - \alpha_r) = \{ \sigma q U \delta k_y \sec \gamma \cos (\gamma + \alpha - \alpha_r) \} / (1 - \sigma \delta k_x) U$$

$$\text{i.e., } \tan (\alpha - \alpha_r) = (\sigma q \delta k_y) [1 - \tan \gamma \tan (\alpha - \alpha_r)] / (1 - \sigma \delta k_x)$$

and

$$\therefore \tan (\alpha - \alpha_r) = (\sigma q \delta k_y) / \{ 1 - \sigma \delta k_x (1 - q) \}$$

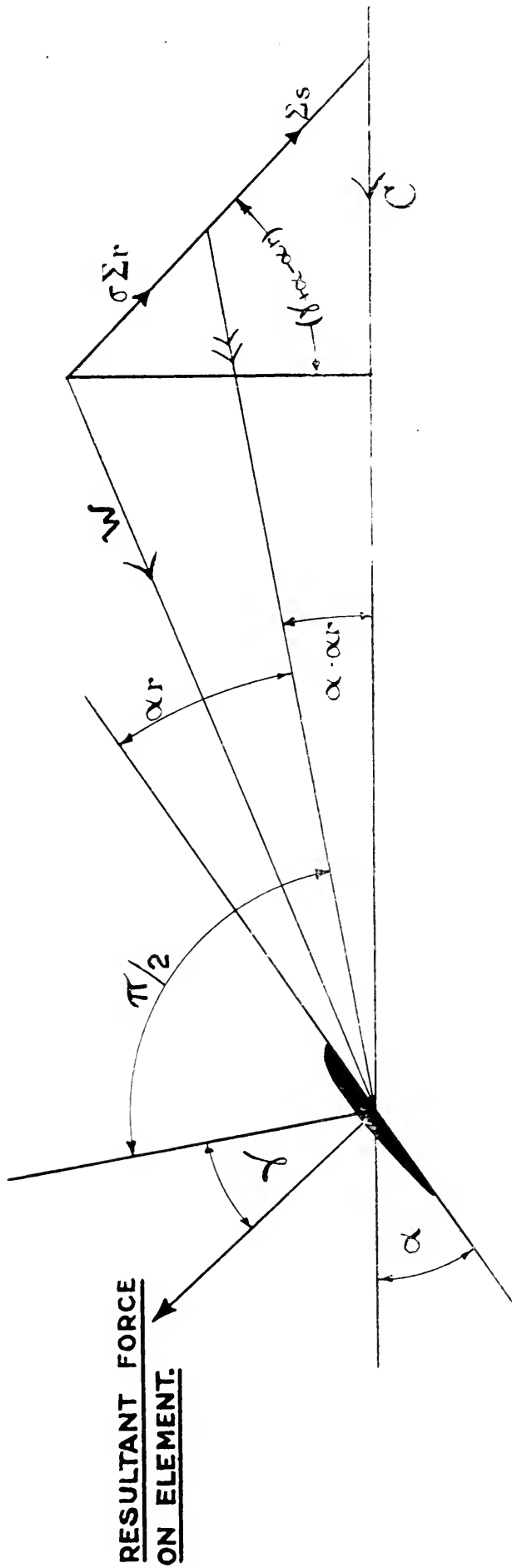
But to the same degree of approximation previously employed this becomes:—

$$(\pi/180) (\alpha - \alpha_r) = (\sigma q \delta k_y) / \{ 1 - \sigma \delta k_x (1 - q) \}$$

which gives the value of α_r in terms of q , since $k_y = f(\alpha_r)$.

Now we can further simplify this result by assuming an equation for k_y in terms of α_r . For many types of aerofoils it is found that the lift coefficient is nearly a straight line from the angle of no-lift up to the stalling angle, so that let us put $k_y = m(\alpha_r - \beta)$, where m is a constant for the aerofoil defined by

FIG. 5.



$\delta k_y / \delta a_r = m$, and β is the angle at which k_y vanishes, *i.e.*, the angle of no-lift of the aerofoil.

Then

$$(\pi/180)(\alpha - \alpha_r) = \{ \sigma q \delta m (\alpha_r - \beta) \} / \{ 1 - \sigma \delta k_x (1 - q) \}$$

Now k_x appears in the denominator and is associated with a term having a very small value compared to unity, unless q is very large in value. Hence, we can tentatively neglect this term and write sufficiently approximately:—

$$(\pi/180)(\alpha - \alpha_r) = \sigma q \delta m (\alpha_r - \beta)$$

giving

$$\alpha_r = (\alpha + \lambda q \beta) / (1 + \lambda q)$$

where

$$\lambda = (180/\pi) \sigma \delta m.$$

This is the general solution for α_r for the static case of propeller action.

Now before we can find the numerical value of α_r in any case we require to know the value of $q\lambda$, *i.e.*, the value of $q\sigma\delta$, since the value of m is known from the aerofoil shape. This unknown product can be settled experimentally if we make the substitution for q :—

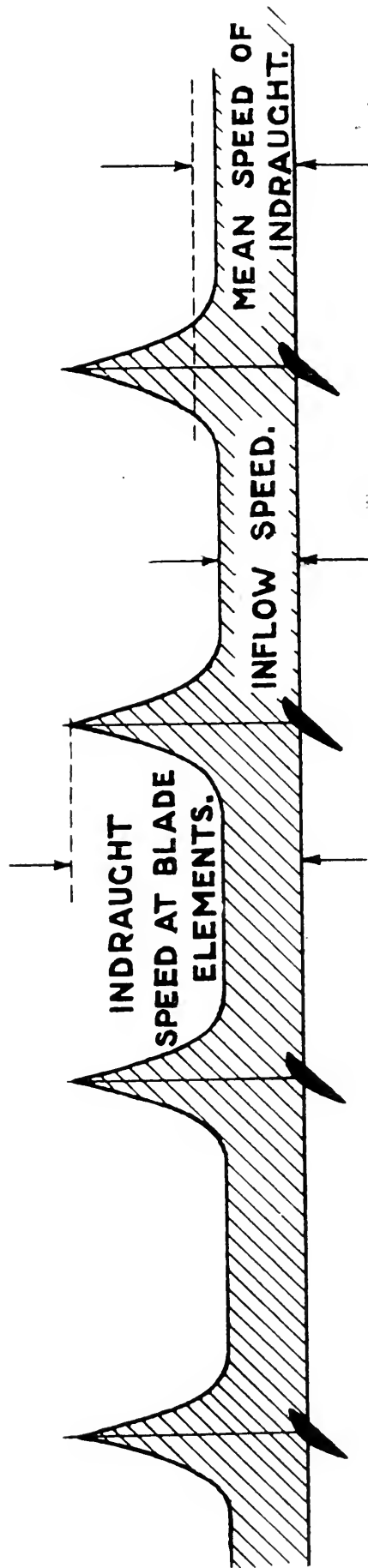
$$q = k (Nb/x), \text{ so that } q\sigma\delta = \sigma\delta k (Nb/x).$$

And we can find the value of $\sigma\delta k$ from our experiment. Then, knowing the value of $\sigma\delta k$, we know the value of $q\sigma\delta$ in any case and hence know the value of α_r in any case. Note that q , σ and δ do not change in value with change of the angle of incidence.*

Consider now for a moment the derivation of q . The inflow velocity at any member of the series after the $(r + q)$ th member is constant and is the sum of a certain (variable) number (q) of the impressed velocities at the members immediately in front (to the right) of it (Fig. 4). Thus, the inflow velocity at the $(r + q)$ th member is the sum of the impressed velocities at the $(r + q - 1)$ th, $(r + q - 2)$ th, . . . r th members. And the inflow velocity at the $(r + q + 1)$ th member is the sum of the impressed velocities at the $(r + q)$ th, $(r + q - 1)$ th, . . . $(r + 1)$ th members. Hence the inflow speed at any member after the $(r + q)$ th member is simply the sum of the impressed velocities at the q members immediately in front of it, and the point to notice is that this does not in general involve in this sum the impressed velocity at *any one* member such as the r th member. If we take a member sufficiently far down (to the left of) the series after the $(r + q)$ th member, the impressed velocities at the r th, $(r + 1)$ th, etc., members do not contribute to the inflow speed at the member chosen because they are too far away to affect it. So that if we now ask the question, what is the speed of indraught (total flow speed) at *any* point on the circumference of any annulus on the disc circle, we cannot say it is the same thing as the indraught at any blade element because the indraught here is the sum of the inflow speed and the impressed speed at the blade element, which *impressed* speed forms a part of the *inflow* speed at the *next* blade element round the annulus. So that it seems probable that the indraught speed into any annulus is a maximum at the blade elements and a minimum between the blades. However, in view of the constancy of the inflow speed and the remarks made above, it seems reasonable to suppose that the *mean* indraught into any annulus approximates to the *inflow speed* and that the indraught speed at the blade elements is *very local* and falls off rapidly to the inflow speed value even close to the blade elements, which value it maintains over the annular circumference until the next blade element is reached when it again rises in value to the sum (inflow speed + impressed speed). Fig. 6 illustrates what is meant. We shall then tentatively assume the *mean* speed of indraught into any annulus on the disc circle to be approximately equal to the

* Strictly this should read " q and $\sigma\delta$, etc."

FIG. 6.



ANY ANNULAR CIRCUMFERENCE ON DISC CIRCLE.

inflow speed at the blade elements for the same radii.* Notice, in passing, that if the angle of incidence α_r is equal to

$$\alpha_r = \{ \alpha + \frac{1}{2} \delta m \beta (180/\pi) \} / \{ 1 + \frac{1}{2} m \delta (180/\pi) \}$$

which is quite a possible value, for we have already seen that $\sigma \delta = \pi/9$ is of the right order of value and we know that the value of σ lies between zero and unity, so that the value of δ lies between infinity and $\pi/9$, giving:—

$$\alpha_r = \beta, \text{ when } \delta = \text{infinity}$$

$$\text{and } \alpha_r = (\alpha + 10m\beta)/(1 + 10m), \text{ when } \delta = \pi/9.$$

A usual value for m being $m = .05$, we get:—

$$\alpha_r = (\alpha + \frac{1}{2}\beta)/1.5 \text{ or } \alpha_r = \beta$$

as the two extreme cases. Neither of these extreme cases, and therefore no case intermediate between them, is in any way an impossible one, so that the above solution for α_r is quite a reasonable one. But this solution for α_r corresponds to $\sigma q = \frac{1}{2}$, i.e., it corresponds to the inflow/slip ratio, having a value of one-half. This value is of the right order and will be familiar to students of the old "inflow theory." Hence, again we notice that the theory given here gives results of the right order in value. We can now find the values of the axial thrust and the torque of the whole propeller. We write dT for the thrust and dQx for the torque on the blade element. The total thrust of the propeller is then:—

$$NT = N \int (\delta T / \delta x) dx,$$

and the power

$$NH = 2\pi nN/550 \int (\delta Q / \delta x) x dx$$

in the lb. ft. sec. system of units. So that we now proceed to find $\delta T / \delta x$ and $\delta Q / \delta x$. From Fig. 5 it is evident that

$dT = dR \cos(\gamma + \alpha - \alpha_r)$, where dR = resultant force on blade element, and $dR = k_y \sec \gamma \rho b dx U^2$, by the ordinary aerofoil equation.

Hence, $dT = \cos(\alpha - \alpha_r) [1 - \tan \gamma \tan(\alpha - \alpha_r)] k_y \rho b dx U^2$,

i.e., $\delta T / \delta x = \cos(\alpha - \alpha_r) [1 - \tan \gamma \tan(\alpha - \alpha_r)] k_y \rho b U^2$.

But from the geometry of Fig. 5 we have:—

$$U \sin(\alpha - \alpha_r) = \Sigma_s \cos(\gamma + \alpha - \alpha_r)$$

and

$$U \cos(\alpha - \alpha_r) = C - \Sigma_s \sin(\gamma + \alpha - \alpha_r)$$

and

$$\therefore \tan(\gamma + \alpha - \alpha_r) = \{ C - U \cos(\alpha - \alpha_r) \} / \{ U \sin(\alpha - \alpha_r) \}$$

giving

$$U = C / \{ \cos(\alpha - \alpha_r) + \sin(\alpha - \alpha_r) \tan(\gamma + \alpha - \alpha_r) \}$$

This gives:—

$$U = C \cos(\alpha - \alpha_r) [1 - \tan \gamma \tan(\alpha - \alpha_r)]$$

and

$$\therefore \delta T / \delta x = \cos^3(\alpha - \alpha_r) [1 - \tan \gamma \tan(\alpha - \alpha_r)]^3 k_y \rho b C^2,$$

$$\text{i.e., } \delta T / \delta x = C^2 k_y \rho b \{ 1 - \tan \gamma \tan(\alpha - \alpha_r) \}^3 / \{ 1 + \tan^2(\alpha - \alpha_r) \}^{3/2}$$

$$= C^2 k_y \rho b \{ 1 - 3 \tan \gamma \tan(\alpha - \alpha_r) \} / \{ 1 + 3/2 \tan^2(\alpha - \alpha_r) \}$$

Approximately, since both $\tan \gamma \tan(\alpha - \alpha_r)$ and $\tan^2(\alpha - \alpha_r)$ are small compared to unity.

Hence

$$\delta T / \delta x = C^2 \rho b \{ k_y - 3k_x \tan(\alpha - \alpha_r) \} / \{ 1 + 3/2 \tan^2(\alpha - \alpha_r) \}$$

$$= C^2 \rho b \{ m(\alpha_r - \beta) - k_x (\pi/60)(\alpha - \alpha_r) \} / \{ 1 + (3/2)(\pi/180)^2 (\alpha - \alpha_r)^2 \}$$

* This assumption is not required for the theory generally. It is used only in evaluating θ in the last part of the Paper.

to the same degree of approximation as before, and substituting for k_y in terms of a_r in the approximate equation:—

$$k_y = m (a_r - \beta)$$

Hence $(\delta T/\delta x)$ is found in terms of the radius (x) and the angle (a_r), which latter is known already in terms of the angle of the blade and q . The values of $(a_r - \beta)$ and $(a - a_r)$ are then evidently:—

$$a_r - \beta = (a - \beta)/(1 + \lambda q);$$

and

$$a - a_r = \{ \lambda q (a - \beta) \} / \{ 1 + \lambda q \}$$

Then by substitution:—

$$\delta T/\delta x = C^2 \rho b (a - \beta) (1 + \lambda q) \{ m - (\pi/60) k_x \lambda q \} / \\ \{ (1 + \lambda q)^2 + (3/2) (\pi/180)^2 \lambda^2 q^2 (a - \beta)^2 \}$$

giving $(\delta T/\delta x)$ in terms of λq , etc.

Now

$$\lambda q = (180/\pi) \sigma \delta m k (Nb/x) \\ = (180/\pi) m (Nb/x) \sigma \delta k \\ \text{i.e., } \lambda q = (180/\pi) m (Nb/x) \theta,$$

say where

$$\theta = \sigma \delta k.$$

So that θ , or $\sigma \delta k$, becomes now the only unknown quantity in the equation. Since also the term $(\pi/60) k_x \lambda q$ is small compared to the term (m) because it is of equal ratio to (m) to the ratio

$$k_x (\pi/60) (a - a_r)/k_y$$

which is small compared to unity, except for the case when k_y is in the neighbourhood of β the "no lift" angle—an ordinary value being of the order of $1/15$ —we may in many cases treat it only as of the order of a correction and hence assume the value of k_x to be constant with the blade radius. This is a simplification in many cases.

Then substituting for λq in $\delta T/\delta x$, we get:—

$$\delta T/\delta x = C^2 \rho b m (a - \beta) \{ 1 + \theta (180/\pi) m (Nb/x) \} \{ 1 - 3\theta k_x (Nb/x) \} / \\ [\{ 1 + \theta (180/\pi) m (Nb/x) \}^2 + (3/2) \theta^2 m^2 (a - \beta)^2 (Nb/x)^2]$$

This is the formula for the axial thrust of any type of fan. The only unknown quantity is seen to be θ , and later the value of θ will be determined to a first approximation.

By a similar process we now proceed to find the value of the torque, *i.e.*, we find the expression for $\delta Q/\delta x$. The circumferential component of the force reaction on any blade element is given by:—

$$dQ = dR \sin (\gamma + a - a_r) \\ = \sin (\gamma + a - a_r) k_y \sec \gamma \rho b dx U^2$$

$$\text{i.e., } \delta Q/\delta x = \cos (a - a_r) [\tan \gamma + \tan (a - a_r)] k_y \rho b U^2 \\ = \cos^3 (a - a_r) [\tan \gamma + \tan (a - a_r)] k_y \rho b C^2 [1 - \tan \gamma \tan (a - a_r)]^2 \\ = C^2 k_y \rho b \{ \tan \gamma + \tan (a - a_r) \} \{ 1 - \tan \gamma \tan (a - a_r) \}^2 / \{ 1 + \tan^2 (a - a_r) \}^{3/2} \\ \text{i.e., } \delta Q/\delta x = C^2 k_y \rho b \{ \tan \gamma + \tan (a - a_r) \} \{ 1 - 2 \tan \gamma \tan (a - a_r) \} / \\ \{ 1 + (3/2) \tan^2 (a - a_r) \}$$

Approximately as before,

$$\begin{aligned} i.e., \delta Q/\delta x &= C^2 \rho b \{ k_x + k_y \tan(\alpha - \alpha_r) \} \{ k_y - 2k_x \tan(\alpha - \alpha_r) \} / \\ &\quad k_y \{ 1 + (3/2) \tan^2(\alpha - \alpha_r) \} \\ &= C^2 \rho b \{ k_x + m(\pi/180)(\alpha_r - \beta)(\alpha - \alpha_r) \} \{ m(\alpha_r - \beta) - k_x(\pi/90)(\alpha - \alpha_r) \} / \\ &\quad m(\alpha_r - \beta) \{ 1 + (3/2)(\pi/180)^2(\alpha - \alpha_r)^2 \} \end{aligned}$$

substituting as before. Then

$$\delta Q/\delta x = C^2 \rho b \{ k_x(1 + \lambda q)^2 + m(\pi/180)\lambda q(\alpha - \beta)^2 \} \{ m - k_x(\pi/90)\lambda q \} / \\ m \{ (1 + \lambda q)^2 + (3/2)(\pi/180)^2 \lambda^2 q^2 (\alpha - \beta)^2 \}$$

Hence, substituting for λq as before, we get finally:—

$$\begin{aligned} &\delta Q/\delta x \\ &= C^2 \rho b [k_x \{ 1 + \theta(180/\pi)m(Nb/x) \}^2 + m^2(\alpha - \beta)^2 \theta(Nb/x)] [1 - 2k_x \theta(Nb/x)] / \\ &\quad [\{ 1 + \theta(180/\pi)m(Nb/x) \}^2 + (3/2)m^2(\alpha - \beta)^2 \theta^2(Nb/x)^2] \end{aligned}$$

This is the formula from which the power is obtained for any type of fan, the torque being $\int x(\delta Q/\delta x) dx$ for each blade. As for the axial thrust formula, the only unknown quantity is θ .

Experimental Determination of θ .

It is evident that $\Sigma_s = C \sec \gamma \sin(\alpha - \alpha_r)$. And the vertical component, *i.e.*, the component velocity normal to the screw disc, of Σ_s is $\Sigma_s \cos(\gamma + \alpha - \alpha_r)$. Hence, denoting this normal velocity component by Σ'_s , we have:—

$$\begin{aligned} \Sigma'_s &= \Sigma_s \cos(\gamma + \alpha - \alpha_r) \\ &= C \tan(\alpha - \alpha_r) \{ 1 - \tan \gamma \tan(\alpha - \alpha_r) \} / \{ 1 + \tan^2(\alpha - \alpha_r) \} \\ i.e., \Sigma'_s &= C(\pi/180)\lambda q(\alpha - \beta)(1 + \lambda q) \{ m - k_x(\pi/180)\lambda q \} / \\ &\quad m \{ (1 + \lambda q)^2 + (\pi/180)^2 \lambda^2 q^2 (\alpha - \beta)^2 \} \end{aligned}$$

in terms of λq to the same order of approximation. And

$$\therefore \Sigma'_s = mC\theta(Nb/x)(\alpha - \beta) \{ 1 + (180/\pi)m\theta(Nb/x) \} \{ 1 - k_x\theta(Nb/x) \} / \\ [\{ 1 + (180/\pi)m\theta(Nb/x) \}^2 + (\alpha - \beta)^2 m^2 \theta^2(Nb/x)^2]$$

in terms of the radius x and the unknown quantity θ .

Now compare this result with the formula for $\delta T/\delta x$; and notice that, since the terms in the denominators involving $(\alpha - \beta)^2$ are very small in practically every case, we can neglect them in both formulæ for a first approximation in finding a tentative value for θ . Then approximately:—

$$\Sigma'_s = mC\theta(Nb/x)(\alpha - \beta) \{ 1 - k_x\theta(Nb/x) \} / \{ 1 + (180/\pi)m\theta(Nb/x) \}$$

And similarly for $\delta T/\delta x$ approximately:—

$$\delta T/\delta x = C^2 \rho b m(\alpha - \beta) \{ 1 - 3\theta k_x(Nb/x) \} / \{ 1 + \theta(180/\pi)m(Nb/x) \}$$

Now since

$$\begin{aligned} mC(\alpha - \beta) / \{ 1 + \theta(180/\pi)m(Nb/x) \} \\ = \Sigma'_s / \theta(Nb/x) \{ 1 - k_x\theta(Nb/x) \} \end{aligned}$$

$$\therefore \delta T/\delta x = C\rho b \{ 1 - 3\theta k_x(Nb/x) \} \Sigma'_s / \{ \theta(Nb/x) [1 - k_x\theta(Nb/x)] \}$$

in terms of Σ'_s .

Hence, if we have any experimental fan which has a constant value of Σ'_s for all radii x we can employ the above formula to find the thrust of the fan, and conversely, if we know the thrust of the fan and the value of Σ'_s we can determine the value of θ . Further, it is evident that for all "good" angles of incidence α_r , $\tan \gamma$ is small compared to unity and $\tan \gamma \tan(\alpha - \alpha_r)$ is very small

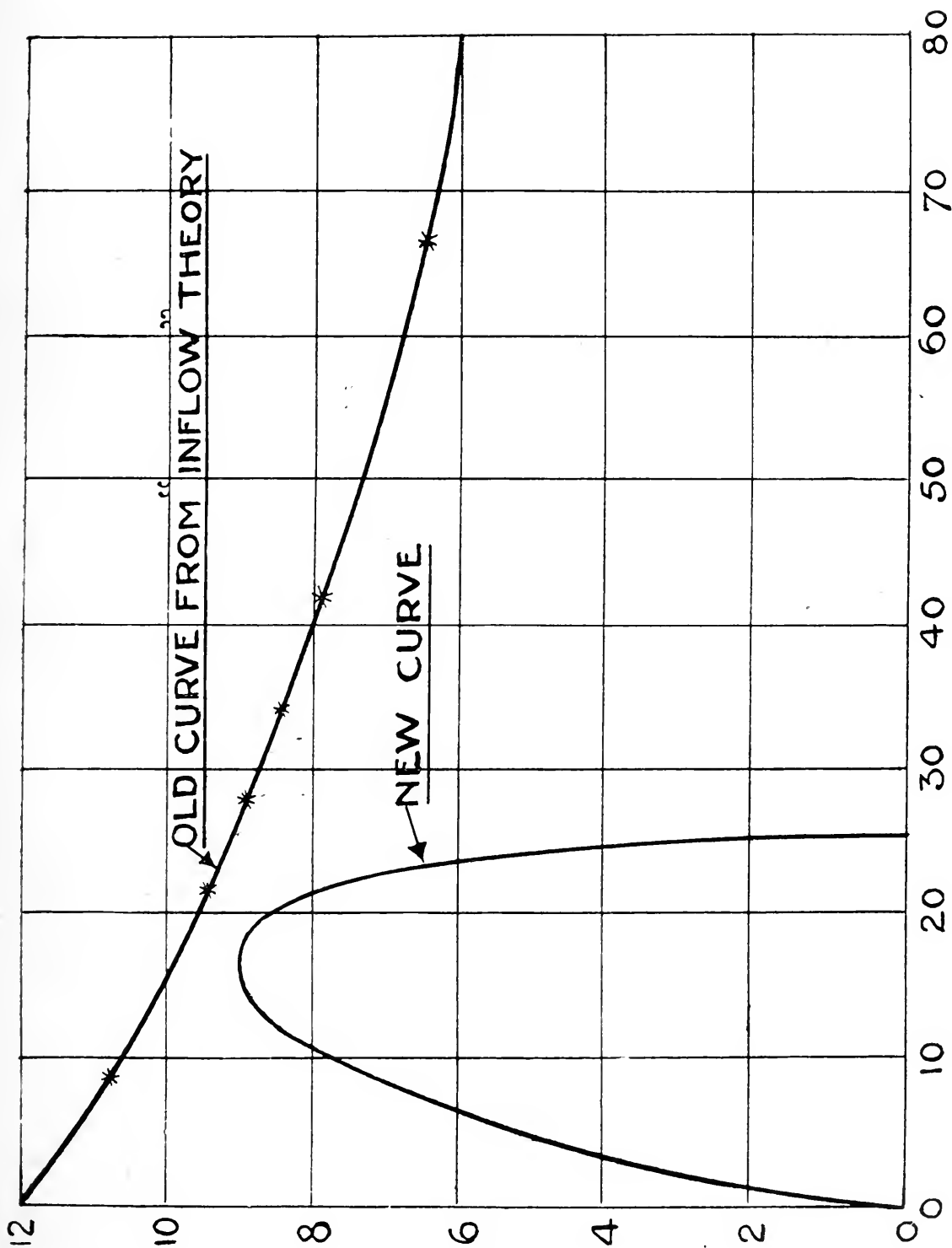


FIG. 7.

except quite near the boss where the thrust is vanishingly small, so that a further approximation gives:—

$$\delta T/\delta x = C\rho b\Sigma'_s/\theta (Nb/x),$$

and \therefore

$$\theta = \rho\Sigma'_s/T \int bCdx/(Nb/x)$$

from which the value of θ is at once found. Some years ago I made and tested two wooden fans, both of which were geometrically identical and of equal diameter. The diameter was three feet. One was a two-bladed and the other a four-bladed fan. They both gave identical results on test as near as I was able to measure at the time. In each fan the product (chord blade width \times number of blades) was the same and equal to $4/3$ feet, so that the four-bladed fan had blades one-half the chord width of the other. The chord blade width was constant along the blade length. The r.p.m. was in each case 1,050, the power being supplied by an electric motor of 0.6 b.h.p. rating running at 1,400 r.p.m., the reduction to the fan being by a flat belt drive of 3:4 reduction. The axial thrust recorded was a trifle over 12lbs., and the speed of in-draught normal to the screw disc was found by an anemometer to be approximately constant with blade radius and equal to about 16 feet per second.* The speed of out-draught was measured as about double this figure. From these admittedly rather rough test results I propose now to calculate the value of θ as a first tentative estimate.

$$\begin{aligned}\theta &= \rho\Sigma'_s/T \int bCdx/(Nb/x) \\ T &= 12\text{lbs.}/N = \text{thrust per blade.} \\ &= (.00237 \times 16 \times 2\pi \times 17\frac{1}{2})/(12) \int_0^{3/2} x^2 dx \\ &= (.00237 \times 16 \times 2\pi \times 17\frac{1}{2} \times 27)/(12 \times 3 \times 8) = .391.\end{aligned}$$

Hence, $\theta = .391$ as a first rough estimate.

Conclusions.

The theory enunciated above has been developed in order to, if possible, take the place of the "inflow" theory of the airscrew, which latter is too empirical, although the present paper is concerned only with the special case of the propeller working at a fixed point, without axial motion, after the manner of a fan. The theory given here is based upon blade interference and nothing else, and is amalgamated with and forms a correction upon the original "blade element" theory of Drzewiecki. It requires further development so as to include the general case of propeller action, but it is thought that the present paper will have achieved its main object if it draws attention to the fact that the "inflow" theory being admitted to be of too highly empirical a nature, a theory can be evolved which shall possess the same power in application as this older theory and which, at the same time, shall rest upon a more rational basis. The key and corner stone of the new theory is blade interference, the regime of which has only recently begun to be understood in its relation to all screw propeller action. Not only does this new theory not require the assumption—upon which the "inflow" theory depends—that the inflow/slip ratio is a constant, but it shows that this ratio varies and how it varies, the form of which variation is confirmed by experiment.

* Or slightly greater. It is here assumed that this figure is approximately equal to the normal inflow speed component.

APPENDIX.

From the two equations, when Σ_s' is a constant with radius:—

$$\delta T / \delta x = (C \rho b \Sigma_s') / \theta (Nb/x),$$

and

$$\delta Q / \delta x = \rho b [C^2 k_x + (\Sigma_s')^2 / \theta (Nb/x)],$$

we can determine the thrust T in terms of the power H and propeller diameter D . Assume constant blade width b . Then:—

$$NT = 2\pi n \rho \Sigma_s' / \theta \int_0^{D/2} x^2 dx = (2\pi n \rho \Sigma_s' / 3\theta) (D^3/8)$$

$$NT = (\pi n \rho \Sigma_s' D^3) / (12\theta) = \text{total axial thrust of propeller.}$$

And

$$\begin{aligned} N(\delta Q / \delta x) x &= \rho Nb C^2 k_x x + (\rho \Sigma_s'^2 x^2) / \theta \\ NH &= 2\pi n N / 550 \int (\delta Q / \delta x) x dx = 2\pi n \rho / 550 \int [Nb C^2 k_x x + (\Sigma_s'^2 x^2) / \theta] dx \\ &= 2\pi n \rho / 550 [Nb k_x 4\pi^2 n^2 \int_0^{D/2} x^3 dx + (\Sigma_s'^2 / \theta) \int_0^{D/2} x^2 dx] \\ &= 2\pi n \rho / 550 [(Nb k_x \pi^2 n^2) (D^4/16) + (\Sigma_s'^2 / 3\theta) (D^3/8)] \\ &= 2\pi n \rho / 550 [(Nb k_x \pi^2 n^2 D^4/16) + 6\theta (NT)^2 / \pi^2 n^2 \rho^2 D^3] \end{aligned}$$

and

$$\therefore 6\theta (NT)^2 / \pi^2 n^2 \rho^2 D^3 = 550 (NH) / 2\pi n \rho - Nb k_x \pi^2 n^2 D^4 / 16$$

and

$$\therefore (NT)^2 = \{ (550 (NH) / 2\pi n \rho) - (Nb k_x \pi^2 n^2 D^4 / 16) \} (\pi^2 n^2 \rho^2 D^3 / 6\theta)$$

This gives the axial thrust of any fan, of constant chord blade width and constant normal component of inflow speed, in terms of blade width.

Suppose we put $Nb = \phi D$, so that the total blade width becomes a fraction (ϕ) of the propeller diameter D . Then we get, writing W for the total axial thrust (NT) and H for the total BHP instead of NH .

$$W = \{ \pi^{\frac{1}{2}} n^{\frac{1}{2}} \rho^{\frac{1}{2}} D^{3/2} \sqrt{550} H^{\frac{1}{2}} / \sqrt{12} \theta \} \sqrt{ \{ 1 - (\phi k_x \pi^3 n^3 D^5 \rho) / 8.550 H \} }$$

Now I have previously shown elsewhere* that the thrust of any fan or helicopter can be represented by:—

$$W = \rho^{\frac{1}{2}} H^{\frac{3}{2}} D^{\frac{3}{2}} f(n D^{5/3} \rho^{\frac{1}{2}} / H^{\frac{1}{2}})$$

So that by equating these two equations we can find the form of the unknown function f . This gives:—

$$f(n D^{5/3} \rho^{\frac{1}{2}} / H^{\frac{1}{2}}) = (550 \pi / 12 \theta)^{\frac{1}{2}} (n D^{5/3} \rho^{\frac{1}{2}} / H^{\frac{1}{2}})^{\frac{1}{2}} \{ 1 - (\phi k_x \pi^3 / 4.400) (n D^{5/3} \rho^{\frac{1}{2}} / H^{\frac{1}{2}})^3 \}^{\frac{1}{2}}$$

So that, writing ψ for the argument $(n D^{5/3} \rho^{\frac{1}{2}} / H^{\frac{1}{2}})$, we get:—

$$f(\psi) = (550 \pi / 12 \theta)^{\frac{1}{2}} \psi^{\frac{1}{2}} \{ 1 - \phi k_x \pi^3 \psi^3 / 4.400 \}^{\frac{1}{2}}$$

And the form of the function $f(\psi)$ is hence determinate and both ψ and $f(\psi)$ are non-dimensional.

Now I have shown elsewhere that if we take

$$F(\psi) = \rho^{\frac{1}{2}} f(\psi)$$

so that

$$W = H^{\frac{3}{2}} D^{\frac{3}{2}} F(\psi)$$

the value of $F(\psi)$ is round about 8 for many cases.

* "The Helicopter Flying Machine," *Aircraft Engineering*.

Now in this new theory we find that the corresponding value of $F(\psi)$ is given by:—

$$F(\psi) = \rho^{\frac{1}{2}} (550 \pi / 12 \theta)^{\frac{1}{2}} \psi^{\frac{1}{2}} \{ 1 - \phi k_x \pi^3 \psi^3 / 4400 \}^{\frac{1}{2}}$$

where the value of ρ is the "ground level" value of .00237, and $\rho^{\frac{1}{2}} = 1/7.5 = 2/15$, so that

$$F(\psi) = (2/15) (550 \pi / 12 \times 391) \psi^{\frac{1}{2}} \{ 1 - \phi k_x \pi^3 \psi^3 / 4400 \}^{\frac{1}{2}}$$

with $\theta = .391$ as found already. Then

$$F(\psi) = 2.56 \psi^{\frac{1}{2}} \{ 1 - \phi k_x \pi^3 \psi^3 / 4400 \}^{\frac{1}{2}}$$

Now in order to get an idea of the order of values let us take some rough values for ϕk_x . Let $k_x = 1/60$, $\phi = \frac{1}{2}$ (not too large for a fan or helicopter), so that

$$\phi k_x \pi^3 / 4400 = 31 / (2 \times 60 \times 4400) = 1/17,000$$

Hence,

$$F(\psi) = 2.56 \psi^{\frac{1}{2}} (1 - \psi^3 / 17,000)^{\frac{1}{2}}$$

showing that for small values of ψ the last term in the equation is only a small correction, but for values of ψ of 20 and over the correction is very material.

We can now form the following characteristic table of values:—

ψ	0	5	10	15	20	25.7
$F(\psi)$	0	5.7	7.83	8.87	8.35	0

This is plotted in Fig. 7, together with the curve obtained from the "inflow" theory and published by me in "The Helicopter Flying Machine" (*Aircraft Engineering*, June, 1920, Fig. 5). It will be seen that although the two curves are so dissimilar in form the values of $F(\psi)$ are of the same order in the two curves in the "useful" region from $\psi = 10$ to $\psi = 20$, and that in this region the value of $F(\psi)$ is round about 8, as mentioned in the article referred to above. Thus, the new theory of blade interference is seen to give results of the right order in this case also.



REVIEW.

Automobile and Aircraft Engines in Theory and Experiment. Arthur W. Judge, A.R.C.S., London. Sir. Isaac Pitman and Sons, Ltd.

This revised and enlarged edition of "High Speed Internal Combustion Engines" will be welcomed by all who are interested in theoretical and experimental work relating to automobile and aircraft engines, since the title truly describes the subject matter, and this is set out very clearly by a writer who is technically sound.

There are thirteen chapters, three appendices and a good index, comprising in all some 640 pages. The first chapter deals with combustion and explosion, and this is followed by an exposition of the thermodynamics of internal combustion engines which includes treatment of variable specific heat and entropy. Next, the real conditions obtaining in engines are compared with those assumed for the purpose of theoretical treatment, and this leads to a comparison of real and ideal thermal efficiencies.

Conduction, radiation, and cooling effects are then considered, after which the measurement of temperature, pressure, volumetric efficiency and power is dealt with at length. Then follows a chapter on altitude effects and supercharging, this portion relating chiefly to aircraft engines, and the mechanics of high-speed engines are then outlined. The last chapter but one is devoted to balancing, and the final chapter to the subject of fuels for automobile and aircraft engines. In Appendix II. the Still engine is described. Appendix III. comprises a table of aircraft engine particulars.

A satisfactory feature of the book is that it contains numerous references to important papers, etc., dealing with particular pieces of research. These references have been brought well up to the beginning of 1921.

The book was, however, issued too soon for reference to be made to the exceedingly valuable articles contributed to "The Automobile Engineer" by Ricardo entitled "The Influence of Various Fuels on the Performance of Internal Combustion Engines," and by Tizard and Pye entitled "The Character of Various Fuels for Internal Combustion Engines." A study of these matters is not now complete without a perusal of the articles referred to, or of the paper read by Tizard in May, 1921, before the North-East Coast Institution of Engineers and Shipbuilders entitled "The Causes of Detonation in Internal Combustion Engines," and on this account they are mentioned here.

Many important and helpful papers in transactions and journals are practically buried until they are epitomised in a book of this kind, and in co-ordinating and summarising the results obtained by various experimenters in this field, Mr. Judge has accomplished a very useful piece of work. Although some of the experiments quoted date back a number of years and were made upon engines which by modern standards were inefficient, they serve to illustrate points of fundamental interest, and their mention is justified on this account.

Messrs. Pitman are to be congratulated on the excellent printing of the text and the clearness of the many graphs, etc.

B. C. C.



PUBLICATIONS.

The following papers, etc., are published by the Society:—

Transactions.

1. "The Calculation of Stresses in Aeroplane Wing Spars," by Arthur Berry, M.A. 5s. od.
2. "Position Fixing in Aircraft during Long Distance Flights over the Sea," by Instructor-Commander T. Y. Baker, R.N., and Major L. N. G. Filon, D.Sc., F.R.S., late R.A.F. ... 5s. od.
3. "Aero Engine Efficiencies," by Dr. A. H. Gibson 5s. od.

Aeronautical Classics.

Reprints of the Work of Early Pioneers on whose theories modern flight is based.

1. "Aerial Navigation," by Sir George Cayley (1809) 21s. od.
2. "Aerial Locomotion," by F. H. Wenham (1866) 1s. od.
3. "The Art of Flying," by Thomas Walker (1810) 1s. od.
4. "The Aerial Ship," by Francesco Lana (1670) 1s. od.
5. "Gliding," by Percy S. Pilcher (1897) 1s. od.
6. "The Flight of Birds," by G. A. Borelli (1680) 1s. od.

Miscellaneous Publications.

- "Steels Used in Aero Work," by Dr. W. H. Hatfield 5s. od.
- "Methods of Measuring Aircraft Performances," by Captain H. T. Tizard 1s. 6d.
- "The Screw Propeller in Air," by M. A. S. Riach 2s. 6d.
- "The High Tension Magneto," by A. P. Young 5s. od.
- "Commercial Aeronautics," by G. Holt Thomas 2s. 6d.
- "The Training of Aeronautical Engineers," by R. M. Walmsley and C. E. Larard 2s. 6d.
- "Steel Tubes for Aircraft," by W. W. and A. G. Hackett 2s. 6d.
- "Timber," by W. H. Barling 5s. od.
- "Design of Aeroplane Struts," by W. H. Barling and H. A. Webb ... 2s. 6d.
- "Stress Optical Experiments," by Major A. R. Low 5s. od.
- "Medical Aspects of Aviation," by Dr. L. E. Stamm 2s. 6d.
- "Struts of Conical Taper," by H. A. Webb and Miss E. D. Lang ... 1s. 6d.
- "Shop Practice in Respect to Aircraft Steel," by H. P. Philpot ... 5s. od.
- "The Rigging of Aeroplanes," by R. J. Goodman Crouch 5s. od.
- "Progress of Aviation during the War Period," by Dr. L. Bairstow ... 5s. od.
- "Flight of Seagulls," by Dr. E. H. Hankin 5s. od.
- "Chronology of Aviation," by H. Maxim and W. J. Hammer 1s. od.
- "Report of the Bird Construction Committee" 10s. 6d.
- "Glossary of Aeronautical Terms" 2s. 6d.
- "London-Paris Service. Safety and Economy Committee's Report" 1s. 6d.



THE AËRONAUTICAL JOURNAL.

(FOUNDED 1897 in succession to the ANNUAL REPORTS.)

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 135.

MARCH, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on February 1st:—

Fellow.—John Case.

Associate Fellows.—Sir Arthur Whitten Brown, K.B.E., M.I.E.E.,
M.I.Mech.E., L. J. Jones.

Students.—J. Calderwood, H. Gornes-Cornejo, E. A. Skinner, F. B. Ford.

Member.—David Longden.

Associate Members.—G. Hoare, H. L. Reilly, E. E. D. Smith, C. J. Wood.

Annual General Meeting.

Voting members will shortly receive formal notification of the Annual General Meeting, which is to take place in the Library, at 5.0 p.m., on Wednesday, March 29th. The Council's Annual Report and Accounts for the year 1921, which will be presented to members at the meeting, will be found in this issue.

Students' Section.

The next meeting will take place in the Library, at 7.0 p.m., on Thursday, March 23rd, when Mr. S. H. Evans (Hon. Secretary) will open the discussion with "Some Notes on Commercial Aeroplanes," when Mr. A. V. Roe will take the chair. Professor L. Bairstow, C.B.E., F.R.S., Fellow, has kindly consented to give the first annual lecture to the Students' Section in the Library, at 7.0 p.m., on Friday, April 7th, on "Some Aeronautical Problems of the Early Future."

The following paper has been read since the last announcement:—February 23rd, Mr. G. R. Irvine, "Some Possible Improvements in Aero-Engine Installation." Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., Associate Fellow, took the chair.

Associate Fellowship.

The Council have decided to accept the Diploma in Aeronautical Engineering of the Engineering Day College at the Northampton Polytechnic Institute as exempting from the paper in Aerodynamics under the Rules of Examination for Associate Fellowship.

Arrangements for the Month.

- March 2, 5.30 p.m. Lecture by Mr. W. D. Douglas, Associate Fellow, on "Testing Aircraft to Destruction," at the Royal Society of Arts, John Street, Adelphi.
- „ 16, 5.30 p.m. Lecture by Dr. V. E. Pullin on "Radiological Inspection Work."
- „ 21, 4.0 p.m. Library and Publications Committee.
- „ „ 4.30 p.m. Candidates Committee.
- „ „ 5.0 p.m. Council.
- „ 23, 7.0 p.m. Students' Discussion Meeting, "Some Notes on Commercial Aeroplanes," by Mr. S. H. Evans (Hon. Secretary). Mr. A. V. Roe in the chair.
- „ 28, 5.0 p.m. **Annual General Meeting** in the Library.
- „ 30, 5.30 p.m. Lecture by Capt. G. de Havilland, on "The Design of a Commercial Aeroplane."

W. LOCKWOOD MARSH, *Secretary*.



57th ANNUAL REPORT OF THE COUNCIL, 1921—1922.

Council.

Chairman: Lieut.-Col. M. O'Gorman, C.B., D.Sc.

Vice-Chairman: Air Cmdre. H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C.

Brig.-Gen. R. K. Bagnall-Wild, C.M.G., C.B.E., Prof. L. Bairstow, C.B.E., F.R.S., Major F. H. Bramwell, Wing Cmdr. T. R. Cave-Browne-Cave, C.B.E., Sir M. D. Chalmers, K.C.B., C.S.I., Sir Robert Hadfield, F.R.S., Capt. G. de Havilland, O.B.E., A.F.C., Prof. B. Melville Jones, A.F.C., Major A. R. Low, Lieut.-Col. J. T. C. Moore-Brabazon, M.C., M.P., Lieut.-Col. A. Ogilvie, C.B.E., A. J. Sutton Pippard, D.Sc., A. V. Roe, O.B.E., Col. The Master of Sempill, A.F.C., Major R. V. Southwell, Lieut.-Col. H. T. Tizard, A.F.C., Brig.-Gen. J. G. Weir, C.M.G., C.B.E., Major H. E. Wimperis, O.B.E., A. E. Turner (*Honorary Treasurer*).

On April 19th, 1921, the Council unanimously elected Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., as the first Vice-President of the Society under the new rules, in recognition of his long service as chairman and devotion to the Society's interests. Sir Mackenzie Chalmers, K.C.B., C.S.I., was co-opted to the vacancy thus left in the Council.

The Council are glad to say that the improved financial position which they foreshadowed in their last annual report has been to a considerable extent realised and the Society has been successful in making its income cover its expenditure during the last twelve months. This result has been achieved by the closest economy wherever possible, coupled with the increase in the subscriptions rendered necessary by the serious position which was revealed two years ago. It must, however, be pointed out that the anticipated increased revenue from the new contract for advertisements in the JOURNAL has not been realised, owing partly to the prevailing trade depression and partly to the effects of the old contract, which, though it expired on January 1st, 1921, still leaves certain liabilities.

The report of the Honorary Treasurer in regard to the situation will be found in a later paragraph.

It may confidently be said that the general position of the Society continues to improve owing to a greater part having been taken in the various aeronautical activities. Such movements as the Safety and Economy Committee, the Deputation to the Air Minister on the subject of research, and the institution of more stringent regulations for admission to the technical grades of the Society have undoubtedly enhanced the Society's reputation.

Membership.

The membership numbered 879 on January 1st, 1922, compared with 1,002 at the same date last year; a position which may be considered not unsatisfactory in view of the many calls on individuals at the present time. All subscriptions owing prior to January 1st, 1921, have now been written off and the same course has been followed as to 50 per cent. of those still outstanding for the year 1921. Experience has shown that this view is to a certain extent pessimistic, but it has the advantage of preventing disappointment in the future. The amount of outstanding subscriptions at the end of any single year has in fact fallen very con-

siderably, and improved office organisation has definitely resulted in more prompt payment and the cheaper collection of arrears, so that the number of members is now a criterion of the income.

Representation on Other Bodies.

An invitation has lately been received from the Secretary to the Air Ministry to nominate a representative on the newly formed "Civil Aviation Advisory Board" and Colonel O'Gorman has accordingly been appointed by the Council to serve on that body.

It is desired to tender thanks to the following gentlemen for kindly acting as the Society's representatives on the following committees:—

- B.E.S.A. Nomenclature Committee.—Prof. Bairstow, Major Low, Lieut.-Col. O'Gorman, Dr. Sutton Pippard, Major Southwell and the Secretary.
- Joint Standing Committee with the S.B.A.C.—Chairman (ex-officio), Vice-Chairman (ex-officio), Prof. Bairstow, Wing Cmdr. Cave-Browne-Cave, Lieut.-Col. A. Ogilvie, Lieut.-Col. M. O'Gorman and Major-Gen. Sir R. M. Ruck.
- Conjoint Board of Scientific Societies.—Lieut.-Col. O'Gorman.
- Aeronautical Research Committee.—Lieut.-Col. Ogilvie.
- British Engineering Standards Association.—Lieut.-Col. O'Gorman.
- Advisory Committee on Aeronautical Education.—Lieut.-Col. O'Gorman.

Scottish Branch.

The membership of the Scottish Branch now numbers 67. During the year the Honorary Secretary addressed a number of classes in Glasgow University, including an aggregate of some 900 students.

A very interesting programme of lectures has been held as follows:—

- 1921.
 - Sept. 19th.—Mr. Norman Yarrow, "Commercial Aviation in Canada." Lord Weir in the chair.
 - Oct. 3rd-Oct. 8th.—Sir Ross Smith's Lecture.
 - Oct. 17th.—Col. V. C. Richmond, O.B.E., "The Organisation of a Colonial Airship Service." Lord Invernairn in the chair.
 - Oct. 31st.—Prof. Gordon Gray, D.Sc., "Research Work in the Application of Gyroscopes to Aviation." Brig.-Gen. J. G. Weir in the chair.
 - Nov. 14th.—Major-General Sir Hugh Trenchard, Bart., K.C.B., "Auxiliary Aids to the Royal Air Force." Lord Weir in the chair.
 - Dec. 12th.—Col. Gold, "The Application of Meteorology to Aviation." Sir John Hunter, K.B.E., in the chair.
- 1922.
 - Jan. 23rd.—Brig.-Gen. Bagnall-Wild, C.M.G., C.B.E., "Engine Installation." Sir John Reid, D.L., in the chair.
 - Feb. 27th.—Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., M.I.Mech.E., "Special Light-Weight Engines." Professor Mellanby, D.Sc., in the chair.

Safety and Economy Committee.

In March, 1921, the Council appointed a committee to discuss the question of the type of engine and mechanical arrangements, etc., required for the safe and economical working of an aeroplane carrying mails and passengers between London and Paris. The following gentlemen served on this committee, which held a number of meetings and issued a valuable report which was published by the Society and was most favourably received:—Lieut.-Col. M. O'Gorman (Chairman), Lieut.-Col. L. F. R. Fell, Capt. G. de Havilland, Capt. G. T. R. Hill, Major G. H. Norman, Mr. H. Ricardo, Mr. A. J. Rowledge, Col. F. Searle, Mr. McKinnon Wood, Col. W. A. Bristow, and Wing Commander J. H. A. Landon. This report

was followed by an interesting paper by General Bagnall-Wild on the subject of "Engine Installation" and enhanced official interest in this question.

Associate Fellowship Examinations.

Following upon the adoption at the last general meeting of members of the Council's new regulations for the admission of Fellows and Associate Fellows the Candidates' Committee has drawn up a detailed syllabus for the Society's examinations for Associate Fellowship and a list of qualifying exemptions. These have been adopted by the Council and issued. It is felt that the completion of this work is an important event in the history of the Society as it provides definite technical qualifications by which the standing of applicants for Associate Fellowship can be tested.

Research.

A number of special meetings of the Council have been held recently to consider the best steps to adopt to ensure the continuance of an adequate measure of applied scientific research by the Government and to prevent a continuance of this being submerged under *ad hoc* experimentation—a growing tendency towards which has been evident in the past. These meetings culminated in a deputation being formed, the personnel of which consisted of Col. O'Gorman (Chairman), Prof. L. Bairstow, Sir Mackenzie Chalmers, Prof. Melvill Jones, Lieut.-Col. A. Ogilvie, and the Secretary, who waited on the Secretary of State for Air, on January 17th last, and laid before him a memorandum drawn up by the Council (*vide* AERONAUTICAL JOURNAL, February, 1922, page 43). The result of this interview may be said to have been so far satisfactory that the Secretary showed himself sympathetic. A statement contained in the official paper on "The Progress of Research", and the trend of the resulting discussion, at the Air Conference show that the Council was voicing a general feeling on this point and it is hoped that this action will have good results.

Students' Section.

The Council have felt that efforts should be made to provide better facilities for Student members of the Society to exchange views than is given by their ordinary university or college courses and by attendance at the Society's lectures. A series of monthly Students' Discussion Meetings have therefore been held in the Society's library during the past winter and have met with considerable support, which, owing to the efforts of the Hon. Secretary, appears to be increasing. It was felt that the objects desired would be best achieved by placing the conduct of these meetings entirely in the hands of, and confining the attendance to, students and guests whom they might themselves invite. This has therefore been the case, with the exception that a member of the Society has been invited by the Students to take the chair at each meeting to give any assistance that might be required. Messrs. Stanley H. Evans (Hon. Sec.), Leslie J. Jones and W. H. Rossiter have been elected by the Students as a small committee to make the necessary arrangements, and the following papers have been read:—

Oct. 13th.—T. A. Kirkup on "A Comparison of Different Types of Aero-foils." Mr. H. B. Irving in the chair.

Nov. 10th.—W. L. Le Page on "The Soaring Flight Problem." Mr. F. Handley Page in the chair.

Jan. 26th.—C. Daniel on "Some Practical Points in Fuselage Construction." Mr. J. D. Frier in the chair.

Feb. 23rd.—G. R. Irvine on "Some Possible Improvements in Aero-Engine Installation." Mr. A. E. L. Chorlton in the chair.

In connection with this scheme a fund has been raised sufficient to provide an annual prize to the amount of about £5 for the best paper inaugurating discussion at one of these meetings in any year. This is to be known as "The Percy Pilcher Memorial Prize for Students."

R.38 Memorial Research Fund.

The effects of the Government decision to close down all operations and research work on airships, which had already been the subject of protest by the Council to the Air Ministry, were brought home by the lamentable accident to R.38. The Council decided that the men who were lost in this airship could best be commemorated by something in the nature of endowment of research work in connection with airships in order that there may not be complete cessation of technical development in this country. "The R.38 Memorial Research Fund" was accordingly started and has at present reached the figure of £1,200. The fund remains open and, it is hoped, may in time become considerably augmented. In the meantime Prof. L. Bairstow, Wing Cmdr. T. R. Cave-Browne-Cave, Major R. V. Southwell and Major H. E. Wimperis have been appointed a committee to consider the best method of carrying out the objects of the fund with the money at present available.

Usborne Memorial.

A small sum has been privately subscribed to provide an annual fee for a lecture on an airship subject in memory of the late Wing Commander Neville F. Usborne, who was killed while carrying out an important experiment in 1916.

Lectures.

The Wilbur Wright Memorial Lecture was read on April 12th, 1921, by Mr. G. I. Taylor, who contributed a most interesting paper on "Scientific Methods in Aeronautics."

The programme of the ordinary monthly lectures since the last annual report has been as follows, and the Council desire to thank all the gentlemen concerned for their contributions to the Society's Proceedings:—

1921.

Oct. 6th.—"Some Notes on Aeroplanes in Tropical Countries," Air Cmdr. H. R. M. Brooke-Popham.

Oct 20th.—"The Langley Machine and the Hammondsport Trials," Mr. Griffith Brewer.

Nov. 3rd.—Manœuvres of Getting Off and Landing," Sqdr. Ldr. R. M. Hill.

Nov. 17th.—"Requirements and Difficulties of Air Transport," Colonel F. Searle.

Dec. 1st.—"The Present Technical Position of Airships," Major G. H. Scott.

Dec. 15th.—"Development of the Fighting Aeroplane," Capt. F. M. Green.

1922.

Jan. 5th.—"Specialised Aircraft," Wing Cmdr. W. D. Beatty.

Jan. 12th.—"Boats that Fly" (Juvenile Lecture), Major D. C. M. Hume.

Jan. 19th.—"Aeroplane Installation," Brig.-Gen. R. K. Bagnall-Wild.

Feb. 16th.—"Methods of Instruction in Aeroplane Flying," Sqdr. Ldr. C. F. A. Portal.

Mar. 2nd.—"Testing Aircraft to Destruction," W. D. Douglas.

And the following gentlemen whose lectures will complete the present Session:—

Mar. 16th.—"Radiological Inspection Work," Dr. V. E. Pullin.

Mar. 30th.—"The Design of a Commercial Aeroplane," Capt. G. de Havilland.

Provincial Lectures.

The Council desire to thank the gentlemen who have kindly lectured on behalf of the Society before the following provincial engineering societies:—

Leeds Association of Engineers.—Mr. F. E. Cowlin on “Airworthiness.”

Coventry Engineering Society.—Mr. H. L. Stevens on “Full Scale Research on Aeroplanes.”

Nottingham Society of Engineers.—Capt. G. T. R. Hill on “The Control of an Aeroplane.”

Finance.

The Honorary Treasurer reports:—For the year 1921 the Income and Expenditure Account shows a credit balance of £136 17s. 11d. as against a deficiency for 1920 of £481 3s. 4d. This result is even more favourable than was forecasted in the last report, and now that the Society's current finances are shown to be in a sound position there would appear to be no reason why the special effort then suggested should not be made to increase the reserve fund of the Society by at least £1,500, that being the extent to which the fund had to be depleted to make good the deficiencies of the two preceding years.

It is regretted that the new advertisement contract for the Journal referred to in last year's report, not only failed to realise the increase then anticipated, but has actually resulted in a reduction of the revenue received from this source by over £850. The final result recorded in the preceding paragraph, however, can only be regarded as all the more satisfactory on this account. The accounts have this year been prepared by the Society's own staff; this arrangement being not only more economical, but more satisfactory in every way.

Honorary Officials.

The cordial thanks of the Society are due to Mr. B. Woodward, who has continued to act as Honorary Solicitor, and to Mr. A. E. Turner, whose advice as Honorary Treasurer has helped in no small measure to the attainment of a more satisfactory financial position.

Journal.

The Council would like to express their gratitude to Mr. J. L. Pritchard, the Editor, who devotes much of his own time to the Journal for an honorarium which he is kind enough to remit as a donation towards the Society's funds. The interest and value of the Journal has undoubtedly improved very much since Mr. Pritchard undertook the post of Editor, as is shown by the increase in outside subscriptions and sales, which has been very marked of late.

Staff.

The Society has been fortunate in retaining the services of the Secretary and the office staff, who have worked together with undiminished zeal to further its interests.



AERIALBALANCE SHEET,
£ s. d. £ s. d.

Dr.

To Nominal Capital—

Divided into 20 Shares of 1/- each and 999 Shares
of £1 each 1,000 0 0

„ Capital issued and called up—

17 Shares of 1/- each 0 17 0

„ Sundry Creditors 692 8 5

„ Subscriptions received in advance 63 11 0

„ Reserve Fund—

Entrance Fees and Life Compositions of present

Members as at 31st Dec., 1920 2,562 16 0

Receipts for 12 months to 31st Dec., 1921 65 2 0

2,627 18 0

Less—Payments 12 12 0

2,615 6 0

Deduct—Income and Expenditure Account

Deficiency at 31st Dec., 1920 ... £1,542 19 11

Less—Surplus of Income over Ex-
penditure for year to 31st Dec.,

1921 136 17 11

1,406 2 0

1,209 4 0

£1,966 0 5

INCOME AND

£ s. d.

To Office Rental, Light and Insurance	328 4 2
„ Salaries	1,188 13 5
„ Exhibitions and Meetings	84 10 11
„ Printing and Stationery	130 18 4
„ Postages and Messengers	95 2 4
„ Library Expenses	15 16 5
„ Office Expenses	78 15 5
„ Donations	1 13 0
„ Income Tax	20 5 0
„ Audit Fee	10 10 0
„ Journals and Pamphlets	202 16 11
„ Subscriptions written off	82 5 6
„ Balance, being surplus of income over expenditure	136 17 11

£2,376 9 4

SCIENCE, LTD.

31st DECEMBER, 1921.

	Cr.	£	s.	d.	£	s.	d.
By Office Furniture, etc.—							
As at 31st Dec., 1920	355	16	8			
Less—Insurance Claim	50	0	0			
					305	16	8
„ Stock of Journals, etc.				359	9	9
„ Stock of Stationery				26	6	6
„ Sundry Debtors, including subscriptions owing				256	12	6
„ Investments at cost—							
£100 5% War Bond	100	0	0			
£783 6s. 5% War Loan Inscribed Stock, 1921/47	725	13	6			
					825	13	6
„ Cash in Bank and on deposit				171	0	1
„ Cash in hand				21	1	5

£1,966 0 5

We report to the Shareholders that we have examined the books of the Society and have obtained all the information and explanations we have required. We are not in a position to judge the value put upon the outstanding subscriptions. Subject to this remark, we are of an opinion that such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of your information and the information given to us and as shown by the books of the Society.

(Signed) PRICE, WATERHOUSE & Co.,
18th February, 1922. 3, Frederick's Place, Old Jewry, E.C.2.

EXPENDITURE ACCOUNT.

	£	s.	d.
By Annual Subscriptions ...	2,331	9	4
„ Interest on War Loan and deposit ...	45	0	0

£2,376 9 4

PROCEEDINGS.

SIXTH MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held in the Rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, December 5th, 1921. Major H. E. Wimperis presided.

The CHAIRMAN, opening the proceedings, called upon Wing-Commander W. D. Beatty, C.B.E., A.F.C., to read his paper.

Wing-Commander W. D. BEATTY then read the following paper:—

SPECIALISED AIRCRAFT.

Introduction.

My subject to-night, specialised aircraft, is one capable of a wide variety of interpretations; so wide, in fact, that when I had to tackle the problem I found much difficulty in deciding which of the many possible lines I should take.

However, I realised that the congregation has no say in the sermon, and that your only alternatives were to stay or to walk out. I propose, therefore, to inflict upon those who choose to stay a short account of how aircraft (heavier than air) have been developed in England on specialised lines, followed by some remarks on the special requirements for commercial work, more particularly in respect to those points of design in which the fare-paying user is intimately concerned. In fact the passenger's comfort is really the main subject of this paper.

I would like here to emphasise the fact that I am addressing you to-night entirely in my personal capacity. If, therefore, you dislike my views cast your stones at me and not at the department to which officially I belong.

Military Development.

The development of aviation from its early stage of the hobby of an enthusiastic few to being the pre-occupation of an ever-growing number of serious users has, until recently, been entirely upon military lines.

I will therefore refer briefly to the specialised types of aircraft thus produced to meet military requirements.

The first serious attempt in England to obtain aircraft designed with a definite use in view was made ten years ago, when on 14th December, 1911, conditions were published by the War Office for a competition, to be held the following summer, for aircraft to comply with a military specification. Many of you here to-night may remember all the details of that competition, but for the benefit of those who are not acquainted with them I will give a summary of the specification with which designers endeavoured to comply.

Military Competitions, 1912.

Machines were to be two-seaters capable of carrying a live load of 350lbs. in addition to fuel for $4\frac{1}{2}$ hours.

Top speed was to be not less than 55 m.p.h. with full load. Climb to 1,000 feet was to take not more than five minutes and preferably not more than $3\frac{1}{2}$ minutes. Angle of glide was not to be steeper than 1 in 6. Dual control,

good view for occupants downwards to front and sides and ability to land on and rise from rough ground were also required. Interchangeability of parts, and details in regard to transport by road and rail were also specified, and the engine was to be capable of being started by the pilot alone. In addition to these conditions certain "desirable attributes" were also outlined.

While the main conditions that I have already quoted would be child's play to an aircraft designer nowadays, some of these additional "desirable attributes" are not even yet incorporated in our modern machines, although their desirability has certainly not decreased. These additional points were as follows:—

1. Stand still with engine running without being held. Except in a few special cases this is now ordinary practice.
2. Effective silencer.
3. Self-starter.

Both these are still conspicuous by their absence on machines now in use. A beginning has, however, been made with self-starters and promising experimental work has been done on silencers.

4. Ease of control:—Considerable strides have been made in this direction, but even so, definite knowledge as to how this can be ensured in the original design appears to be lacking—if we are to judge by the amount of experimental work still frequently found necessary on a new type in order to improve its controllability.
5. Wide range of speed:—Considerable progress has been made in this respect, though further improvement is still anticipated.
6. Good glide with wide range of angles of descent:—Little need be said on this point, though new shapes of aerofoils still occasionally present unexpected difficulties such as reaching the stalling point suddenly on a small reduction in speed.
7. Ease of assembly:—Here considerable improvement is still possible, and I am under the impression that much more attention has been given to this by German designers than by those in England.
8. Stability in flight:—Though much progress has been made, much yet remains to be done and many gaps in our knowledge have yet to be filled by research work and experiment.

At the time these conditions were published they were criticised in many quarters as being too severe. Actually, of 25 competitors, ten were placed by the judges' committee in order of merit, and the first five of these had not been specially designed for the competition. The qualities asked for were, in fact, the attributes of a successful aeroplane and only in a secondary sense military requirements.

In the light of our present knowledge the large majority of the competing machines were highly dangerous, and I doubt if any of our specialist test pilots nowadays would risk getting off the ground in them; indeed, a considerable percentage of the competing machines actually broke in the air later on. Details of the first four machines are given in Table I.

A machine designed at the Royal Aircraft Factory, Farnborough, the famous B.E.2, though naturally not eligible as a competitor, was put through the various tests, and showed itself generally superior to the actual competitors. It was eventually adopted as one of the standard types for the R.F.C.

This was actually the first machine which, arriving from England in a case, was assembled at the Aircraft Park, and flown to the front as a reinforcement early in September, 1914. Within a mile or two of the spot where this photo-

graph (not printed) was taken, Wilbur Wright, six years before, had made his first flight in Europe and proved that the reports of his doings in America were based on fact and not on journalistic imagination.

At the outbreak of war the R.F.C. was equipped with machines intended for general utility work and reconnaissance in particular. Such things as fighting in the air had been thought of, but until experience was gained in the actual use of aircraft in war the lines upon which development was most urgently required could not be determined.

Very rapidly was the required knowledge gained, with war as the instructor, and the design of aircraft for special purposes made big strides. Performance, field of view, offensive armament, manœuvrability, essential equipment, were the main characteristics in the various specifications, the relative importance of each item varying with the purpose for which the machine was required. More, and always more, of each special quality was the cry of the users in the field, pitted as they were against a foe pressing on with similar development, and frequently producing types which for a time surpassed those with which our pilots were equipped.

As on the land, so on the sea the pressure of stern necessity forced on the development of seaplanes designed for various purposes, and of modified land machines for flying off ships.

Thus, by the end of the war the following types were in use. Compare their performances with that specified for the competition in 1912 and you will see the strides made in the six years that followed (Table II.).

This then had been the development on specialised lines produced by war demands from the original "general purposes" specification of 1912. Fifty-five m.p.h. at ground level had become 136 m.p.h. at 15,000ft., climb to 1,000ft. in five minutes had become a climb to 15,000ft. in under 12 minutes, load of crew, fuel, etc., of some 620lbs. had become some 8,490lbs. according to whether speed, climb, or weight carrying was the characteristic specially demanded. Indeed, the speed and climb given above had been attained with a load only some 40lbs. less than that required for the general purpose machine of 1912. Side by side with these improvements in performance had gone improvements in controllability, stability, field of view, strength and general utility. Nor was development limited to the details I have here given, which refer to machines actually in use by the R.A.F. at the close of the war, and which take no account of later types which at that time were in the experimental stage. The figures I have given are, however, an adequate guide to the progress made. The most notable advance, however, was that made in the design and construction of engines.

In 1912 no prize-winner in the military trials used a British engine; at the outbreak of war all our military machines were equipped with French engines. At the end of the war the majority of our machines had engines of British design and construction, though a certain number of French built engines were in use and a number of British built engines of French design, while one American engine was also employed.

Such use of foreign engines was, however, due to the output of engines in England being insufficient to meet the demand—partly as a result of the demands on the factories for other purposes—and not because suitable engines of British design and construction did not exist. Indeed, progress in this respect has been so marked that France has now returned the compliment and arranged for the construction in that country of one of the latest engines of British design—the Napier "Lion."

As regards horse-power, the judges in the 1912 competition remarked of the 120 h.p. Austro-Daimler, fitted in the Cody machine, "This powerful engine seemed to work satisfactorily." The recollection of some of you may also go back to a somewhat heated discussion at Brooklands in the early days, as to

whether it was safe to fit in a monoplane such a high-powered engine as the 50 h.p. Gnome.

Engines of 600 h.p. to 750 h.p. are now actually in use, while the 1,000 h.p. engine is well on its way.

Civil Development.

Having glanced back over the effects produced on the development of aircraft by specialising to meet military requirements, let us now see what has been done as regards aircraft for more peaceful pursuits and the special requirements which commerce demands.

It was not till in the forcing-house of war much fruit of knowledge had been gathered that the science of aeronautics reached a point where it could usefully play a part in the ordinary business of the world. And when peace came, even enthusiasts in aviation knew little of how best to utilise their knowledge. Possible uses and abuses had to be considered in the light of their effect upon the normal life of mankind and safeguards introduced to protect the man in the street from those who desired to live and work in the air above him. The discussion of the terms of peace gave a unique opportunity for obtaining the views of various nations upon these difficult points. On all sides it was realised that aviation eliminated frontiers and that its control was an international matter. General rules of universal application were therefore drawn up and the agreement reached in the International Air Convention recognised, regularised and encouraged commercial communication by air between nations.

In England, the short distances and existing highly developed communications by road and rail offered little chance of obtaining sufficient paying traffic to this new, and as yet commercially untried form of conveyance.

There did, however, appear to be a field worth opening up for pleasure flying, which was at once taken up by various enterprising spirits. Experience soon showed the lines upon which catering for the public taste in this direction could be made to pay, and after three years a certain number of hard-working pilots are still gaining a livelihood from this form of aviation. Low first cost, good flying qualities, and ease of maintenance were the main qualities required in machines for this purpose. Although various ex-war machines have been so employed, the Avro—the standard training machine at the end of the war and now—is that which fills the position in the large majority of cases.

It was to the cross-Channel routes that those desirous of establishing regular air services devoted their serious attention.

A large existing traffic by rail and sea, suffering the inconveniences and discomforts due to the changes from rail to boat and boat to rail and the sea crossing, offered a reasonable prospect that adequate paying loads might be obtained by the air services.

The first organised services were operated with machines of war type, variously modified to meet civil requirements. The demand for aircraft of a special design to meet commercial needs was, however, very early in making itself felt. While aerodynamic requirements are similar in aircraft for both war and peace, other characteristics have entirely different weight placed on them and civil aircraft tend to diverge widely from those military types to which we have hitherto been accustomed. The commercial importance attaching to certain details of design forces on their improvement in a way that the wasteful habits of war failed to do. All such improvement will re-act to the advantage of military designs.

The evolution of new designs, however, requires money, and it is obvious that the pounds obtainable in peace cannot produce improvement as rapidly as the wartime millions.

In commercial design we are, therefore, now at a stage about equivalent to that of military design at that period of the war when slow two-seaters armed with a rifle or a stripped Lewis gun carried on the general air work of the army. The real commercial machine has not yet been developed.

Progress has, however, been made in the right direction and the following are details of some of these early commercial types. (See Table III.)

It may be said that under less difficult conditions than those prevailing on the continental routes, existing types are commercial propositions. Possibly so; the camel may be a commercial means of transport in eastern deserts, but it cannot be considered such for world-wide purposes, and it is for communication throughout the whole world that aircraft have to be developed if they are to fulfil their obvious destiny.

Let us now study in more detail the special lines upon which aircraft should be developed if their commercial use is to be established on a sound basis. In the first place constructors will be forced to realise that their job is to meet the user's wishes to the best of their ability, and not to provide him with their own idea as something "just as good."

Possibly designers will say that they were harried to death during the war in their endeavours to meet the conflicting desires of various users. There may be something in that contention, but I think it is an undeniable fact that the user's wishes were never fully complied with in detail on any machine that went to the front. Though partly due to war pressure and the necessity of avoiding delay in output, this was mainly due to the fact that the user in war was under orders and had to use what he was given. The fear of "delay in output" was always urged and frequently accepted as a reason why "just as good" should be made to do.

In commerce the same will not apply. If the user is not satisfied—and by user in this case I mean both the operating firm and its paying traffic—then the transport firm will lose its traffic and the constructor will get no more orders.

Commercial Requirements.

Now one way of arriving at the user's view of his machines is to study them from the point of view of the profit and loss account of the operating firm.

Take the expenditure first. This it is obviously desirable to reduce; therefore we require the following qualities in our specialised commercial machine:—

Low first cost.

Economical to maintain.

Economical to run.

By careful design manufacture can be simplified and expensive fittings eliminated. Strength is also required, not only from the point of view of safety, but also in the form of resistance to wear and tear. Moving parts, and friction between them should be reduced to a minimum. Parts which require attention must be easily accessible. The engine in particular must be readily removable either complete by itself or complete with its mounting. This is a point on which I should like to see comparative tests carried out by operating firms. Is it more economical to change the engine by itself or the whole engine and mounting complete? The latter might be the quicker operation, and therefore cheaper in labour costs, but it will have to bear the charges due to the additional capital outlay on spare mountings.

The engine, again, should be capable of running long periods without overhaul. I believe that at present we are getting close to a standard period of 100 hours between overhauls, but we want 300 to 500 hours as a normal working period. Economy in running implies low power, and to get a high useful load for less power improved aerodynamic efficiency is required.

Let us now turn to the receipts side of the account. Naturally it is desired to increase these figures. First, therefore, we must have a large load-carrying capacity. But this capacity is of no avail if the traffic to fill it cannot be attracted. Jonah's whale may have been, and probably was, capable of carrying twenty people quicker than an express train, but can you imagine any useful traffic being attracted to such an uncomfortable and malodorous conveyance?

Passengers' Needs.

You have recently heard in this hall the views of an operating firm as to their detailed requirements in aircraft for commercial purposes. I propose, therefore, largely to neglect that important aspect of the matter and mainly to discuss the special need of the other branch of the users of aircraft, that is the passengers.

Far more attention is necessary to the comfort of passengers, and this embraces a wide variety of detail. I cannot but think that considerable advance might be made in forthcoming commercial types were designers to travel to and from Paris in each of the various types of aircraft actually in use on the cross-Channel services. This is the slack time of the year for passenger traffic; why should not the transport companies grant a certain number of free return tickets to *bona-fide* designers, thus affording them opportunities to ascertain in their own vile bodies the various existing causes of discomfort and learn what to avoid. Passengers are the most important source of revenue for air transport firms at the present time, and each that considers that he has had a really comfortable journey is a walking advertisement for the air line, while each dissatisfied passenger will result in a lowering of possible receipts.

Silence.

First and foremost amongst the important items affecting comfort I would place silence. A "desirable attribute" in 1912, it has never yet been attained in normal practice and the air line passenger still suffers acute discomfort from the noise to which he is subjected.

It is true that the noise in a machine comes from a variety of sources, but it is urgent that some at least should be eliminated. Promising exhaust silencers have appeared experimentally; it is for designers to incorporate them in their designs. Never should an open exhaust point in the direction of the cabin. Get rid of the barking roar of the exhaust and it becomes possible to identify and so to eliminate the other noises. Probably modifications in the design of propellers may be desirable, and with a silent exhaust it becomes an easier matter to compare the noise effect of two different propellers. Fabric covered fuselages must also, I think, be relegated to the past; a stiff wooden covering does not transmit to the interior of the cabin the blows from the slipstream in the same way that fabric does. Vibration and resonance are closely allied to noise in their effect on passengers and should be eliminated. It may be necessary on these grounds to ensure that the two engines of a twin-engined machine never synchronise. I believe Colonel Bristow is trying experiments on these lines. Engine designers will need to utilise motor car experience and get rid of that variety of noises from gears and other moving parts which at present are so obvious in an aero engine when its exhaust does happen to be silenced.

Ventilation and Heating.

The next important detail which designers should carefully study is that of ventilation, to which very little attention has hitherto been given.

Adequate ventilation of the cabins of commercial aircraft is a problem that presents considerable difficulty. The cubic space available is very limited, so that the air inside the cabin tends to become vitiated rapidly, while the speed of

the machine is such that the velocity of in-coming air is often so high that the passenger feels a draught. In rough weather, therefore, the unfortunate passenger tends to suffer from depression, headache, cold and illness.

The monk of old may in time have found his hair shirt to be a comfortable garment, but it is at least probable that at the first time of wearing he desired to remove it; and passengers who are not compelled to do so will not repeat an uncomfortable journey by air.

For many years the efficiency of ventilation has been determined by the quantity of carbon dioxide present in the atmosphere. The supply of air generally recognised as necessary to remove all sensible impurities amounts to 3,000 cubic feet per hour per person. In a present day cabin of 300 cubic feet—seating ten passengers—the air must be changed 100 times an hour if the standard allowance is to be provided. In practice, such a rate of change is unobtainable, except in unbearably draughty conditions.

It is clear then that the measurement of the CO_2 content is likely to continue to give unsatisfactory results in aircraft.

Professor Leonard Hill, however, has pointed out that the 3,000 cubic feet figure can be much reduced if the cooling, drying and radiant energy conditions are satisfactory. To afford a means of determining these conditions he invented the "Kata" thermometer. Experiments have shown that the information given by this instrument is an accurate guide to the adequacy of the ventilation so tested, and if the results obtained from its use average between six and eight the conditions may be considered satisfactory.

Now the cooling and drying effects of air depend largely upon its rate of movement, and it may be taken that if the temperature of the air is 55° to 60° , its velocity at the inlet to the cabin should not exceed $4\frac{1}{2}$ feet per second, if the inlet is 18 inches or more from the passenger, or 3 feet per second if it is less than 18 inches from the passenger.

With inadequate warming arrangements, a change of air more frequently than three to five times an hour is likely to be uncomfortable in the normal cabin, and under such conditions it may be found necessary to keep the velocity of in-coming air down to $1\frac{1}{2}$ to 2 feet per second.

The velocity of out-going air may be as much as 10 feet per second at the orifice, particularly if that is at least 18 inches from the passenger.

Designers should, I think, aim at providing for some twenty changes per hour, taking care to avoid draughts and make satisfactory heating arrangements.

If it is found that the air is being changed too rapidly for comfort, it is a very simple matter to close up some of the openings. It is far more difficult for the user of the aircraft so to alter it as to increase the regular supply of air if the original arrangements have proved inadequate.

Now how is the air to be changed? Experiments in America on sleeping cars showed that, provided the foul air was expelled, an ample supply of fresh air found its way through cracks and crevices in a swiftly moving vehicle.

Personally, I think it better to arrange for the removal of the foul air than to trust to luck to its finding its way out. It should be practicable to design suitable aspirators to draw the air from the cabin of an aeroplane—slightly above the floor level, for, though hot air rises, vitiated air tends to descend. It is probable that air entering through cracks and crevices will do so at such a velocity as to be a source of discomfort to passengers, particularly as its temperature is likely to be low. Air inlets should, therefore, be arranged at the front of the cabin, somewhat below the roof; the velocity of air entering here can readily be governed by the insertion of right angle bends in the trunks leading to the inlets; each such right angle bend reducing the total flow by 50 per cent.

TABLE I.

SUCCESSFUL MACHINES AT THE MILITARY COMPETITION 1912.

Order of Merit.	Type.	Engine.	Speed at Ground Level (m.p.h.)		Climb to 10,000 Mins.	Weight (lb.)		Weight (lbs.) per sq. ft.	
			High.	Low.		Gross.	Load.*	sq. ft.	H.P.
—	Specification		55 (min.)	—	5 (max.)	—	—	—	—
1	Cody	120 h.p. Austro-Daimler	72.4	48.5	3.5	2658	710	5.55	23.8
2	Deperdussin	100 h.p. Gnome	69.1	50.0	3.0	1854	670	6.1	23.4
3	Hanriot	100 h.p. Gnome	75.2	59.9	2.7	1860	701	6.4	24.0
	M. Farman	70 h.p. Renault	55.2	37.4	4.0	1010	601	2.9	26.8
—	B.E.2	70 h.p. Renault	70.0	40.0	2.76	1700	620	4.55	23.5

* Load as here given includes fuel, crew and military load.

TABLE II.

DEVELOPMENT OF SPECIALISED MILITARY AIRCRAFT IN SIX YEARS FROM 1912.

TYPE	ENGINE.	SPEED. m p h at 10,000 ft 15,000 ft 55 at ground level	CLIMB (mins.) 10,000 ft 15,000 ft 1.0-0 in 5 mins	WEIGHT*		LOADING.	
				Gross. SAY 1,800	Load. SAY 1,550	sq ft SAY 6.0	H.P. SAY 24.0
<i>Training.</i>							
Aero 504K.	110 Le Rhone	80	23.6	—	1853	558	5.95 14.5
<i>Fighters.</i>							
Martinsyde F.4	300 H.S.	142.5	6.7	11.8	2280	570	6.05 7.5
S.E.5	200 Viper H.S.	126.	10.8	20.8	1988	520	8.00 9.8
Sopwith Snipe	200 B.R.2	118.	8.8	17.8	1950	710	7.2 8.55
<i>Bristol Fighter</i>							
	275 Rolls	113.	105.	11.8	2848	845	7.00 10.4
<i>Reconnaissance and Day Bombing.</i>							
D.H.4	300 Rolls	130.	124.	11.3	3570	1097	8.2 9.0
D.H.6	210 Siddeley Puma	110.	101.	18.9	3316	1115	7.6 13.8
D.H.6a	400 Liberty	120.	114.	11.8	4220	1450	8.55 16.65
<i>Night Bomber.</i>							
H.P. 6040	2 300 Rolls	84.5	69.0	27.2	13360	4858	8.1 18.6
Vickers Vimy	2 300 Rolls	95.	33.	33.	12500	5390	9.4 17.4
H.P. V. 1500	1 300 Rolls	97. (8750)	18.5	18.5	24700	8190	8.55 17.2
<i>Ship Aeroplanes.</i>							
Sopwith Camel	150 B.R.1	116.	113.	25.	1530	494	6.7 10.2
Parnall Panther	250 B.R.2	103.	—	17.1	2595	1267	8.0 11.4
<i>Torpedo Aeroplanes.</i>							
Sopwith Torpedo	200 Arab	80.	65.0	15.7	3883	1684	6.85 18.75
Blackburn Blackbird	300 Rolls	78.5	80.	16.2	5700	2472	8.35 16.5
<i>Scoutplanes.</i>							
Hamble Baby	110 Clerget	78.	25.	25.	1040	560	7.6 17.4
Short 84	200 Sunbeam	73.	33.8	33.8	5303	1660	7.9 20.8
Fairey 3C.	300 Rolls	40. (2000)	9.5	9.5	4800	1408	10.08 13.5
<i>Flying Boats.</i>							
F.2 A.	2 300 Rolls	80.	16.5	16.5	11084	3362	9.75 16.1
F.5	2 300 Rolls	80.	16.1	16.1	12268	4245	8.7 17.8

* Load as here given includes fuel, crew and military load.

TABLE III.

EARLY TYPES OF COMMERCIAL AIRCRAFT.

Type	Engine	Speed (m.p.h.)		Climb Height in 1,000 ft. seconds	Weight (lbs.)		Weight per sq. ft.	H.P.
		Ground Level.	High.		Gross	Load		
Avro (1912) ...	60 h.p. Green	40.3	—	—	1,762	571	5.28	27.2
Handley Page W.8 ...	2 450 h.p. ... Napier Lion	110	55	—	11,443	3,503	7.86	11.55
Vickers Vimy Commercial ...	2 300 h.p. ... Rolls Royce	103	50	—	12,500	4,025	9.37	17.8
De H. 18 ...	450 h.p. Napier Lion	110	57	—	12,500	4,025	9.37	17.8
15 to 15,000 ft. in 10 mins.								
		110	57	—	12,500	4,025	9.37	17.8

* Load as here given includes fuel, crew and useful load.

the machine is such that passenger feels a draught. ger tends to suffer from

The monk of old may garment, but it is at least to remove it; and passenger uncomfortable journey by

For many years the quantity of carbon dioxide recognised as necessary to feet per hour per person. passengers—the air must be is to be provided. In practice unbearably draughty condition

It is clear then that the to give unsatisfactory result

Professor Leonard Hil figure can be much reduced are satisfactory. To afford the "Kata" thermometer. by this instrument is an accurate and if the results obtained tions may be considered satisfactory

Now the cooling and movement, and it may be its velocity at the inlet to the inlet is 18 inches or more from 18 inches from the passenger

With inadequate warm than three to five times an hour and under such conditions in-coming air down to 1½ to

The velocity of out-going orifice, particularly if that is

Designers should, I think, hour, taking care to avoid draught

If it is found that the a very simple matter to close up the user of the aircraft so to the original arrangements have

Now how is the air to cars showed that, provided the air found its way through cracks

Personally, I think it better to trust to luck to its finding suitable aspirators to draw the the floor level, for, though it is probable that air entering the velocity as to be a source of discomfort is likely to be low. of the cabin, somewhat below readily be governed by the inlets to the inlets; each such right

Ship	Aeroplane	2/360 h.p. Rolls Royce	450 h.p. Napier Lion (5 to 1 compression)	103	50	—	87	26	—	—	—	39.5	11,057	3,267	8.28	15.71
Vickers Commercial	—	—	—	—	—	—	—	—	—	12,500	4,925	9.37	17.8
De H. 18	—	—	120.2	117.2	—	—	5.0	12.3	7,000	2,690	2,690	11.21	16.05

* Load as here given includes fuel, crew and useful load.

It must be remembered that it is essential that the in-coming air should be free from impurities, due to exhaust gases, petrol fumes, stale oil, and so on.

Special arrangements for the aspiration of the air from the engine compartment—which should in any case be bulkheaded off from the passenger cabin—may be of value in preventing leaks of impure air into the cabin.

Heating is closely bound up with ventilation, and at the temperature likely to be met with in ordinary flying it is essential that arrangements should be made for warming the cabin. It is possible to arrange for a supply of air heated by the exhaust pipes, but it should be remembered that air that has been in contact with metal heated to some 200° C. is definitely unsuitable for breathing. Those of you who may have tried to handle a loose exhaust pipe in the air, even with thick gloves, will realise that 200° C. is a low estimate of its temperature. If a muff on the exhaust is used, it should therefore be stepped up, the in-coming air for the cabin being taken from the outer step.

Some of you, however, may remember the footwarmers which Cody fitted to his machine, heated from a bye-pass off the engine cooling system. While there are objections to the introduction of such complications in a matter so important as the running of the engine, no serious difficulty should be experienced in fitting a hot water or steam heating system which draws its heat from the exhaust. Such a system, once developed experimentally, should prove very satisfactory and require little or no attention, while its weight ought not to be excessive.

A suitable arrangement for ventilation and heating might be as follows:—At the forward end of the cabin fresh air enters at a rate of 3 feet per second through an inlet about 12 in. by 12 in. in size, slightly below the roof. Aspirators arranged below the seat level at the back of the cabin suck out the vitiated air. An exhaust heated tubular boiler supplies steam or hot water to a radiator fitted two or three inches in front of the fresh air inlet and the same heating system includes footwarmers in the cabin floor. Such an arrangement should imply fresh air, warmth and comfort for the passengers.

The form of construction of the cabin directly affects its warmth, and from this point of view the fabric-covered cabin is very bad. With this material radiation to the outer air is so rapid that adequate warming in cold weather is almost out of the question.

While comfort, warmth and adequate ventilation will remove some of the causes which predispose to air sickness, other psychological causes will still remain. Here the designer has little say in the matter, but in parenthesis, I may suggest that some thought should be given to occupying passengers' attention. The development of a loud speaking attachment for the wireless telephone might be of advantage; fitted in the cabin it would enable the passengers to hear the remarks passing through the ether, though it might then be found necessary to tone down some of the personal conversation that nowadays takes place between individual pilots. Or the firm's representative who travels in some machines might inaugurate a game of "put and take"—thus making the roughest journey against a head wind pass with rapidity and amusement. Of course, some individuals might consider such preventive measures worse than the disease.

I am indebted to Colonel Heald, the medical adviser to our department, for much of the information upon which the foregoing is based.

Seats.

However, I must return to the subject of passengers' comfort, and I wish to say a word or two about seating accommodation. It always seems to me that chair designers work entirely by tradition, and that if any scientific study of the subject has been made, no attention has been given to the conclusions reached.

If the tyres on the wheels of a motor car are too small, the vehicle is uncomfortable to ride in and the tyres wear out rapidly. Similarly, if the weight of one's body is carried by a small portion of it, that part quickly gets fatigued and the whole body feels uncomfortable.

Only too often seats are designed so that an unnecessarily small portion of one's anatomy bears the majority of the weight. Why should not designers study the problem carefully in conjunction with anatomists and produce a light chair properly designed to suit the human form and to keep the loading per square inch of flesh at a low figure?

Nature of Route.

Many details of design will be affected by the nature of the country over which machines are operating. Aeroplanes, flying boats and amphibians will each have their special fields.

I do not propose to weary you with detail on this point, but I have here some slides showing what has been done experimentally to meet special conditions in snow-covered country. For the photographs (not printed) from which these slides were made I am indebted to Captain F. S. Cotton in regard to those from Newfoundland and to Major C. H. R. Johnstone for that of the Sopwith, which was taken in Sweden.

Number of Engines.

There is room for much diversity of opinion in regard to single engine versus twin engine, or multi-engine machines. While traffic is small the lower first cost and running cost of a single engine machine has an important bearing on the matter. If a twin engine machine will carry nearly double the load of a single engine machine, it immediately becomes a serious competitor economically if the available traffic is sufficient to fill it. Here arises the problem of how large can a fuselage be built practically for a single engine machine. In military aircraft great weight can be carried in a small compass as the load is in a very condensed form. But in commercial types there will be a continual demand for more cubic space per passenger. Will fuselages be necessarily so large that high-powered engines will be economically unsound? In the De H.18, eight passengers are carried at 56 h.p. each; in the De H.32, eight at 45 h.p. each.

Let us assume that we are considering the use in a single engine passenger aircraft of a 1,000 h.p. engine. For that power we must accommodate at least 22 passengers, and we should endeavour to allow at least 40 cubic feet of space per head. Is such a fuselage practicable for a single engined machine? What is the limiting size? How is propeller efficiency likely to be affected? These questions, which also concern the practicable size of twin engine aircraft, are matters on which I feel sure that engine designers would like the considered views of aircraft designers, otherwise they may be devoting their attention to engines of a size likely to be unsuitable for commercial work.

The twin engined machine has some advantages over the single engined, particularly if it will fly on one engine. Greater reliability is thereby secured, and to the psychological desire of many passengers for a machine with more than one engine is added the greater favour with which insurance companies may regard it.

Salvage.

From the insurance point of view, emergency exits for passengers should be provided and the question of salvage is of some importance. Attention to details which facilitate quick repairs in the event of trouble, and easy transport of spare parts, may assist a constructor in obtaining the favour of those august under-

writers, whose opinions are reflected with much emphasis in the balance sheet of the transport firm.

There are, of course, methods of salvage which have been developed entirely independently of the design of the machine, though I doubt whether insurance companies would look with favour upon practices based on the occurrences illustrated in the following slides.

Conclusion.

The development of specialised aircraft on military lines will tend to progress more slowly as less and less money is devoted to military purposes by the various nations. It is by proving its value to the commerce and communications of the world that aviation will really enter upon a period of rapid useful development. If any of my remarks this evening help at all towards the production of the real commercial machine, which will supply to the financiers of the world convincing proofs of the commercial possibilities of air transport, I shall feel amply rewarded.

DISCUSSION.

The CHAIRMAN, after the reading of the paper, said that Wing-Commander Beatty could not have treated the subject in a more illuminating way. To compress so large a subject into such a small compass was a very remarkable achievement.

Sir SAMUEL INSTONE, at the invitation of the Chairman, opened the discussion. He represented, he said, purely the commercial side of aviation. He was not a technical man, and never had posed as such, but they would agree that commercialism was essential to the air industry, and one could not succeed, perhaps, without the help of the other. Looking at the subject with the cold commercial eye might not appeal, perhaps, to those who had devoted their intelligence to the development of aircraft. He begged them, however, to look upon commercialism as a friend and not as an opposing force to the progress of aviation. He had listened with the greatest possible interest to what he might candidly call a remarkable paper, given in a remarkable way by Wing-Commander Beatty. It was particularly encouraging to one like himself, who awaited the arrival of a real commercial aeroplane, but the real commercial aeroplane, to his mind, could not arrive until those engaged in the designing and building of aeroplanes received proper encouragement from the proper quarter. There was no hiding the fact that the progress of aviation depended more and more on money, and the financiers of the city, and elsewhere, and those who had money at their disposal, together with the imagination—for one was very essential to the other—had not the means at the present time to put what they ought to put into this side of aviation, which undoubtedly had an enormous future, and on which, he would go as far as to say, the future of the country would depend. Commerce had been bled white by taxation—he said that with all seriousness, and those who should have, and would have had, ample means for the development of civil aviation, in the same way as the merchants of the City of London developed the Mercantile Marine in days gone by, had not the means at their disposal, having had to make provision for taxation, that the industry had a right to expect. The result was that they must look for encouragement from the proper quarter, and that was the Government. They would say that what the Government spent would re-act upon the taxpayer, and that if they asked for more money they would have to find it on the turn of the wheel. He put it to them that where £16,000,000 was allocated by the Government for aviation, it was incomprehensible that out of that sum a paltry £200,000 was apportioned to civil aviation. When they considered that little countries like Czecho-

Slovakia, and even smaller countries, were putting aside perhaps double what the great British Government was allocating to civil aviation, was it reasonable to expect our designers and builders to keep together their technical staffs and to devote their time and energy to the creation of machines which were to compete in the progress of the world on a paltry £200,000 per annum? That was not all—and here he hoped the author would remember his own words, that he was speaking that evening entirely in his personal capacity, and not for the Government or his Department, and would not take as a personal matter anything he (the speaker) was going to say. Not only was there only £200,000 allocated for commercial aviation, but it seemed to him, in the various interviews he had had with officials, that their ambition in life seemed to be, not how best that £200,000 could be spent, but to see how much they could save out of it. He knew the civil servant had not the freedom of the man in commerce trading on his own account, and he dare say that it was a feather in the cap of anybody who could go to his chief and say that he had saved £190,000 out of that £200,000 (laughter). What was the consequence? It must be that progress was restricted. He would go further and say that where subsidies were granted, it was only natural that there were restrictions, and those in charge being technical men, every one had his little pet theory, and liked to put it into operation and see it tried, and perhaps imposed it upon those with commercial experience; that was hampering. As against that £200,000, the allocation by the French Government meant that the French civil aviation companies had £3,000,000 sterling to play with. Wing-Commander Beatty had thought of all the things that were necessary to make civil aviation the most comfortable, the cleanest and the most pleasant means of travel, but unfortunately they must have assistance. If those present would cast their memories back, at the first Air Conference that was called at the Guildhall he had the pluck to stand up amongst all the experts, and was the only one to speak the truth in that way (laughter) and say that civil aviation was not a commercial proposition. He had said that civil aviation could not pay. He was surrounded by some eminent gentlemen, and one had said that they did not want subsidies and would run a service without. They did; for five minutes, he believed. He had told them that the only remedy must be for the Government to purchase the machines and rent them out on hire to those companies who could run them. What had happened had been precisely what he had predicted; the Government had bought machines and were lending them out to the operating firms. But still, he said again that it was not a commercial proposition, and he would say to anybody, especially any Government servant who thought that there was going to be any profit made out of running those machines, that it was a fallacy. Until things returned more to their normal condition in the City it was only to the Government that those interested in the progress of civil aviation could look. There were one or two points he would like to mention in connection with the remarks of Wing-Commander Beatty. He had said that a certain number of free return tickets should be granted to *bona-fide* designers by the operating companies. On behalf of his own company he would say that they had always done that on demand, but strange as it might appear, they had had very little demand for such facilities. Whenever a demand of that nature had been made, his company had been only too pleased to give a free passage or to grant any facility asked for, and he could make that a promise for the future.

There was one remark he would just like to make *en passant*, and that was that he was rather surprised, and pleased, to see that Wing-Commander Beatty had come to the conclusion that there were certain advantages in twin-engine machines. In discussing the programme for operating their new service, his brother and himself had tried to impress with all possible force that some regard must be paid to the public, if it were the public they were catering for, and he had no hesitation in saying that the public would always travel in a twin-engine machine when it was possible. There was an element of safety, the machine

looked safe, and the public thought they had two chances at least of coming back safely; if one engine failed there was another to carry on, and if the operating companies were going to look after the demands of the public, they should have more support than they were receiving at present. He believed he was right in saying that twin-engine machines were definitely refused to them and single-engine machines imposed upon them; of course, that only applied to the machines which the Ministry were renting to them. Thank goodness his firm had a few pence left to indulge in the development of machines for themselves; but more attention must be paid to the demands of the public, and theories must not be imposed upon those who, by practical experience, had felt the public pulse and knew what the public wanted.

Mr. F. HANDLEY PAGE said that the question of specialised machines for commercial work, in which he was particularly interested, was one that merited a great deal of attention. If one referred back to the early days when motor-cars were first introduced, they were, after all, only horse-drawn vehicles with the horse taken out and the motor put in, and eventually they became specialised transport having a definite characteristic of their own. So, too, he believed they would find in time that commercial aircraft would become very definitely specialised, quite distinct from the early box-kite, string, wires, fabric and so forth, and become vehicles which would have very little head resistance, wires reduced to a minimum, landing carriage pulled up inside possibly, and the body and every detail studied so that no horse-power was thrown away. Then he thought it would be possible to get real reliability in aircraft. No longer would they need an enormous engine running full out all the time, but, once the machine had climbed to the desired height, the engine would be throttled down and run at a half or a quarter its horse-power, and therefore have a longer life. In the ordinary motor-car the horse-power, during the greater portion of the time the engine was running, was a comparatively small portion of that which it could develop as a maximum.

Inside the aircraft, too, greater attention would be paid to the comfort of the passengers. As Wing-Commander Beatty had pointed out, that was one of the major things to be studied. After all, if a passenger paid his fare, he was the individual who, in sufficient quantities, they hoped would make the lines pay, and therefore the question of providing him with sufficient air to breathe, and so forth, was a most important point.

He would like also to extend the invitation to designers to travel on his company's machines. Perhaps his firm might not always have so much room as Sir Samuel Instone (laughter), so that he hoped that on the day when designers applied, the machines would not be overcrowded with passengers (renewed laughter). Some of the gentlemen present had already travelled on his machines.

It was most interesting to him that evening to find the subject of twin-engine machines referred to again, particularly in reference to those who had travelled. He had had an opportunity that afternoon of speaking to a very distinguished member of the Royal Aero Club, whom he was pleased to see present. That gentleman had said that he (Mr. Handley Page) was responsible for the most abominable creation in aviation, namely, the twin-engine machine. That was a thing that he (Mr. Handley Page) knew perfectly well was no good, and never would be any good, said the gentleman referred to, and the sooner all twin-engine machines were off the service so much the better for civil aviation. He (Mr. Handley Page) thought that gentleman must have been speaking as the result of a rather unfortunate occurrence as he had been a passenger, but after all that abuse he had admitted that he would be quite willing to travel again in a similar way if he (Mr. Handley Page) would offer him another seat (laughter).

There were a great many technical details in Wing-Commander Beatty's paper to which one could refer at great length had time permitted. It was of

particular interest to all aircraft designers to see the details which medical evidence had shown to be so necessary for comfort, namely, the heating of the cabins, change of air, and things of that nature. It was to the perfection of those details in a specialised way that success would eventually come in the production of a real commercial aircraft.

Major C. C. TURNER took exception to the lecturer's remark that Great Britain was a country so small that we were handicapped with regard to the length of air routes. The remark had nothing at all to do with the subject of the lecture, but there was a very common impression that Great Britain was too small to run sufficiently long commercial air routes. He merely wanted to say that the distance from London to Glasgow was something like 400 miles, and that there were various routes within the United Kingdom which should, he believed, give scope for commercial air lines. One of the speakers in the discussion had made a very downright and explicit statement that commercial aviation at the moment was not a paying proposition. That was probably the experience up to date, but he himself wanted to put it that commercial aviation had not yet been given a chance. They were running commercial aviation in this country on the basis of one very limited route with a mileage of about 85 or 90 miles—London to Lympne, London to Paris, London to Brussels, and occasionally, he believed, London to Amsterdam. The only subsidised routes were those from London to the Continent. It seemed to him that they were limiting British aviation in a most unfair way, and they could not expect to run a business on the smallest possible basis and make a profit out of it. The only way to run a business was to enlarge the basis as much as possible, get the greatest possible turnover, reduce the proportional overhead charges, and so make a profit. What they were doing now was trying to make civil aviation pay with ten machines running, divided between three or four companies. It was absolutely impossible. He regretted to say that he had failed to discover much in the course of the lecture to justify its title—"Specialised Aircraft." It seemed to him that the discussion had drifted to a general discussion of commercial aviation without much reference to technical matters, but the question of two-engine machines as against single-engine machines had arisen. On that question there was no doubt at all that the public, for some reason or other, preferred to fly in two-engine machines, and whenever they had an opportunity of choosing, they preferred to go in a two-engine H.P. or Vickers rather than a single-engine D.H., or whatever it might be. That preference seemed to him to be based upon a lack of information. A two-engine machine, properly designed, was undoubtedly to be preferred to a poorly-designed single-engine machine, but there were a great number of two-engine machines in operation to-day which did not provide a reasonable margin of safety for the passenger. The subject was capable of discussion from the technical point of view, to differentiate between perfectly sound two-engine types and unsound two-engine types, and he rather regretted that the discussion had drifted away to general air transport problems, instead of being directed towards the technical aspect, which, from the title of the lecture, he thought they were entitled to expect.

Major D. H. KENNEDY said it was of some significance, in view of the fact that Wing-Commander Beatty had devoted so much attention to commercial aviation, that nothing whatever was said about the development of specialised aircraft for the carriage of letters and parcels. That seemed to him significant as showing that our rulers were absolutely devoid of imagination at the present time, and were quite content to leave commercial aviation to struggle along under the most tremendous handicap. If they considered that we had already a very considerable air traffic between two capitals—Paris and London, and that there were people who found it convenient to send parcels of various kinds, then was it too much to suppose that there was a desire to send the same sort of goods quickly between the capital of England and the capital of Scotland? It would

be said that parcels could be sent by rail. When there was no rail they were sent by coach, and before that they were sent by carrier; but in every one of those cases, when they looked back, they would see that somebody had to have faith and imagination, and had first of all to provide the facilities. There was no traffic on a road until a road was provided. If they accepted that as good reasoning, the question was who was to have the faith. They could not expect that faith to come from a commercial company, and they should not expect a commercial company to do it; and therefore they got back to the inevitable fact that it remained for the Government to have imagination and faith to say that we were to have commercial aviation. We must first of all provide the funds and the facilities, then the traffic would inevitably come.

Sir SAMUEL INSTONE interposed that, as regards specialised aircraft, the point raised by Major Kennedy was a very important one, and it might interest Major Kennedy and others to know that his own firm were having constructed three special aeroplanes for the purpose of carrying goods, and goods alone, in order to develop the particular business mentioned by Mr. Kennedy. They had come to the conclusion that passengers did not like to, and ought not to, travel in a luggage van, which present aeroplanes were almost being converted into, and it would perhaps satisfy Major Kennedy to know that something in that direction was being done.

The CHAIRMAN pointed out that little had been said in the discussion about the general question of research. The relation of research to civil aviation was naturally the aspect which struck him most. Mr. Handley Page had compared the aero engine with the motor-car engine, pointing out that the motor-car engine worked most of its time at mere fractions (say, 30 per cent.) of its rated output, whereas the aircraft engine had, especially during the war, been pushed up to 100 per cent., or but little less, and was only now getting nearer the motor-car performance in that respect. The Napier Company had told him that their Lion engine, when on civil aviation service, ran during a normal passage on but 60 per cent. of its rated power. That was a real step towards what, in the motor-car industry, had been shown to be the best way of making an internal combustion engine efficient and reliable, *i.e.*, an internal combustion engine as they now knew it. Were they going to know it in its present form for long? The efforts of research workers were directed towards its improvement in pretty well every conceivable way. For instance, they were dealing with such a purely engineering proposition as conversion to air cooling, a change extraordinarily important for machines which were going to operate over desert countries. That was an instance, from the purely engineering point of view, of what research work was aiming at. At the other end of the scale they had research work on purely scientific lines, such as that on the production of materials of much greater strength in relation to their weight. For instance, it had been shown that steel had a tensile strength of only about one-tenth or so of what it should be in an "ideal" condition. Between two such forms of research as these, the purely engineering and the purely scientific, there was a great body of work to be done which would have a tremendous effect on all aviation; it would have a very big effect on the engineering industry itself, but most important of all, on military and civil aviation. From the civil aviation point of view, however, "silence" was a most important requirement; it was first and foremost. This meant silence in two things—in the exhaust and in the propeller. Silence in the exhaust had been attempted on numerous occasions, and he was glad to be able to say that the simplest form of all of silencing the exhaust was as efficient as any other method that had been tried, however complex. Silencing the propeller was equally important, but the aerodynamic work that was involved was exceedingly difficult, and it was not certain that success could be achieved; it was essential, however, to keep on trying. If that work could succeed, then civil aviation would be enormously advanced in the public esteem. The question

of single versus two-engine machines was too long a story to start at that hour, but he mentioned that schemes for water-cooled engines with horse-power as high as 2,500 were under consideration. He emphasised his very strong feeling that the future of civil aviation was bound up at least as much in the development of research as in the production of financial support from the State.

Wing-Commander BEATTY, replying to the discussion, thanked the meeting for the very kind way in which his lecture had been received. The Chairman had mentioned that research was being carried out in connection with such problems as propeller silencing, and so on, but he would point out that hit-and-miss experiments sometimes leapt ahead of organised research, and he would exhort designers to keep on trying new ideas and methods. With regard to Major Kennedy's remarks, he had not specially considered mail machines in the paper simply because existing machines were far more suitable for goods and mails than for passengers, and the bulk of the traffic at the present time was passengers. He agreed with Major Turner that the title of the lecture did not exactly correspond with what was in it. As to the small size of Great Britain, it would be noticed that he had combined "existing highly-developed communications" with the small size of the country when he referred to the fact that in the past there was little prospect for commercial aviation. He did not say there was no prospect at present. He was sorry to hear that designers had not taken more advantage of Sir Samuel Instone's offer in the past.

At the conclusion of the proceedings a hearty vote of thanks was accorded Wing-Commander Beatty for his paper.

Mr. H. P. FOLLAND (*communicated*): Wing-Commander Beatty's paper is extremely interesting from the point of view of the designer, as it is papers of this description which point out to the designer the essential requirements for aircraft in any particular sphere. In war-time we received criticism on our types from the Air Force in the field; commercially, we look forward to the criticisms of users of commercial aircraft in the same way.

Wing-Commander Beatty mentions the rapid development of military types under war conditions. We must also assume that advancement in design will be more rapid as commercial aircraft are more universally used in such directions as postal aeroplanes, goods-carrying aeroplanes and passenger-carrying aeroplanes.

Wing-Commander Beatty also mentions requirements for the military competition of 1922, and states that a number of these have not yet been incorporated. This may probably be due to a general tendency in designing to obtain the best useful load. The carrying of special silencers, self-starters and intricate ventilation systems will only reduce this useful load when in competition with other designs or against other countries. An alternative to this would be a regulation insisting on self-starters, exhaust silencers and adequate ventilation; the latter is absolutely essential, and could be worked on similar lines to B.O.T. requirements for buildings at the present time. This could be agreed by the Committee.

With regard to the number of engines, I am of the opinion that the single-engine machine, as it stands, is a much safer proposition than the twin-engined machine, the latter meaning extra weight, duplication of the most troublesome systems, such as petrol, water and oil, and also two radiators. Very few of the twin-engined machines with more than half load can fly with one engine. I consider that the question of multi-engines in a cabin, driving two or more propellers, is a more satisfactory arrangement.

Commander Beatty raises the question with regard to the sizes of fuselages with larger cubic space per head in relation to high-powered engines; he also asks whether such a fuselage is practicable for single-engined machines.

I do not think that with engines up to 1,000 to 2,000 h.p. the size of the body should materially affect the propeller efficiency, providing that the cross-sectional area at the engine point is within reasonable limits.

It is rather interesting to note that a machine with a B.R.2 engine has a cross-sectional area of 11 square feet at the cowling. The Napier Lion engine, as fitted in the "Mars I.," which is 450 h.p., has only 6 square feet cross-sectional area to the cowling. The Napier "Cub," which is 1,000 h.p. engine, can be cowled in at the nose at little less than 14 square feet cross-sectional area, this being only 27 per cent. larger area than that of a Scout machine with B.R.2 engine. Therefore, providing the nose of the machine is faired within reason to the body, the propeller efficiency would not, I think, be likely to be affected. In the case of a blunt-nosed machine the question would have to be taken of propeller area to body area, and it would probably mean an extra large size propeller.



BOATS THAT FLY.

Juvenile Lecture, delivered before the Society, January 12th, 1922, by
MAJOR D. C. M. HUME.

“The time has come,” the Walrus said,
“To talk of many things;
Of shoes and ships and sealing wax,
Of cabbages and kings.”

LEWIS CARROLL.

You all know those jolly words from “Alice’s Adventures through the Looking Glass,” and in a measure we are about to push our way through the melting mirror of hearsay to the strange world of wonderful facts, where boats fly, and men think nothing of the sort of ascent that blew the breath out of the poor White King when he received his first dusting in the air. We will talk, you and I, of shoes for aircraft—ships that fly and sealing wax that guards the secrets that have made the British seaplane the greatest example of its kind in all the wide world.

First of all you would like to find out, I know, how aircraft manage to fly at all.

You can find that out easily. Take a large box lid or other flat surface, hold it up vertically before you and run across the room with it. You can feel the air pressure on it opposing your motion. You can *feel* the air. You can realise that air has some substance about it—some density, some reluctance to get out of the way, some stickiness or viscosity as those solemn people called scientists call it.

Now come back again and do the run all over again, only this time hold the lid sloping with its top edge away from you and its lower edge in your waistcoat. This time you will feel a distinct tendency for the lid to lift upwards and fly out of your hands—in fact if you could run fast enough it would do so, or else take you up with it.

That is really how an aeroplane flies. A flat surface is rigged up at an angle to the horizontal and is rushed through the air at such a speed that the air does not get out of the way fast enough, and so the surface climbs over it, *i.e.*, is lifted up vertically. The engine of the aircraft is there to push the planes, etc., through the air at the required speed, the air, not the engine, lifts the aircraft, and the engine serves to keep it lifted by maintaining the forward speed.

It was found out many years ago that we can do considerably better than use a flat plate like the above. If the plate be curved in a special manner—cambered, as it is called—the lift which a given area can produce at a given speed is vastly increased. It was in the actual and scientific investigation of the fact that the famous Wright Brothers did work the pioneer value of which cannot be too strongly admired and remembered.

Now comes a curious fact. If we use such a curved or cambered plane the top side and its camber are of far more importance than the under side, for although there is direct positive pressure from the air on the underside there is now, owing to the shape of the top side, a decided suction or negative pressure on the top side. The curvature has caused the air to rise sharply at the nose of the wing, and it does not fall back to its normal position until just after the wings width, or chord as it is called, has passed—this means the air has produced a suction on the top side, and this helps the positive pressure on the under side, and the lift or upward force on an area of any particular size is thus increased.

Cambered wings at their best angle can be made to give eight or nine times the effect of a plain flat plate wing.

If the plane be sloped up at too great an angle to the direction of flight the effect on the air is no longer regular, the resistance to forward motions is greatly increased, and the air all tumbles about anyhow over the top side of the wing in whirls and eddies, and our useful suction or negative pressure is destroyed—the plane no longer lifts enough, and—if we are in an aircraft—down she comes; the aircraft is said to have “stalled.” However, if she is high enough she can recover as she falls, diving nose downwards, and glide out again in a steady path at an angle to the direction of motion sufficiently small to maintain the necessary lift.

In order to avoid this sort of thing we must be able to control the angle at which our plane or wing is pushed through the air.

For this purpose we have to fit a tail. There is a vertical line along which we can imagine the whole lift of our plane to act—the line of centre of pressure the scientists call it. Our plane and all its supports have some weight, therefore it has a centre of gravity, or a place where all its weight may be imagined to be concentrated. If this centre of gravity is behind the line of lift the plane is on its way to a stall, if the centre of gravity is forward of the line of lift the plane is on its way to a nose dive. To stop it doing either we push out another small plane behind the main plane—a tail to balance it—and this being a fair distance away from our main plane can be a small affair. If we can make this tail lift it will push the main plane angle flatter, if we can make the tail plane loose lift it will drop down and increase the main plane angle. Thus, we have got a fore and aft control, we can dive or stall, “switchback” or fly level.

Incidentally for any given push by our engine the actual speed through the air depends upon our resistance to motion, and, as other parts of the aircraft remain practically the same, this means that our airspeed is according to the sharpness of the angle of our wings. So we have also obtained a *speed* control with our tail.

Now how are we going to turn—because we must turn if we want to come back?

We do this just like any other ship with a vertical rudder, put out at the same place as the tail in order to keep it conveniently small. But here is a little point about rudders that you must remember. They won't turn anything unless there is some fixed vertical surface in front of them—keel fin as it is called. An aircraft with no vertical surface at all except its rudder will not turn a corner, it will only slew round and carry on crabwise in its original direction of flight. So we have to fit keel fin forward of it to give the rudder something to push against, as it were, and so swing the nose round persistently as required to make a turn; this keel fin is usually provided by the body of the aircraft and other natural surfaces of its component parts. That is our directional control.

But if we turn a large weight—a large vehicle say—flatly like this we find a strong tendency for everything to slide outwards of the turn—to skid—you've all noticed this effect going round a comparatively flat corner in a bus or a car—the learned name for it is centrifugal force—well our aircraft will be subject to this and will skid outwards unless we make provision against it. On railways they bank up the track so that the centrifugal force is opposed by direct push on the rails—on motor and cycle racing tracks they bank up the track similarly to oppose this force and keep the vehicles from slipping outwards as they turn. In the air we cannot bank the air up, but we can bank the aircraft up so that any tendency to slip is opposed by the direct push of the wings bluff to the air.

Now, how are we going to do that?

We need to raise one wing more than the other, *i.e.*, one wing must develop more lift than the other. It can do this in two ways—one, if one wing goes faster

through the air than the other; two, if one wing's camber can be altered to increase the lift.

The first of these methods may be called the natural bank, for you will see at once that as the aircraft is turned by its rudder the outer wing's tip is going a lot faster than the inner wing's tip—just as the end men of a rank of soldiers have to speed along pretty lively to keep a line when wheeling, whilst the inside men have to go dead slow—consequently the outer wing develops more lift than the inside one and the aircraft banks.

This may or may not be enough to counteract the centrifugal force—if it is either too much or not enough we must use the second or artificial bank to correct the aircraft as required. To do this we fit the wing with a flap or movable back part, which when pulled down a little (and it only needs a very little) has the effect of sharpening the curvature of the top side of the wing, and thereby increases its lift. As this control is one designed to roll the aircraft it is not fitted all the way along the wing, but only where it will be most useful and most easy to work—as far away from the centre of gravity as possible, *i.e.*, at the wing tips.

So that, if our natural bank is too much or too little, we can modify it now by forcibly deflecting our end flaps or ailerons, as they are called, and correcting our altitude so that no side slipping takes place.

For simplicity we have only talked about one-plane machines—monoplanes—but for mechanical conveniences most aircraft and almost all seaplanes are biplanes. I have not got time to-day to explain to you the advantages of each as I am supposed to be telling you about seaplanes, but the facts we have considered are necessary so that you shall be able to understand just how and why a seaplane flies.

The seaplane is the most natural form of aircraft. Some of the earliest experiments were carried out over the water, because it's a nice safe sort of thing to fall into in case of failure, and because calm water is most uncommonly flat and there is nothing to catch in or fall over.

But a seaplane has to have some features which land aircraft don't have to bother about. Firstly, it must float easily, fully and lively like a cork, it must have every facility for coming away from the water when it wants to fly; it must be able to battle successfully with such rough water as it may be expected to encounter sometimes, *i.e.*, it must be seaworthy, and as the sea water and sea air are both very quick and powerful at rusting or otherwise eating away most metals the question of protection from such corrosion has to be ever before the seaplane designer, who has to do his work with one eye on the water and the other in the air, and the water eye must have a true marine outlook—the sailor vision—the naval understanding.

When a land machine is landed on the land it's down and done with; when a seaplane has settled on the water most of the fun is only just starting.

Seaplanes are of two kinds “shoes and ships”—float seaplanes and boat seaplanes. A float seaplane looks like an aeroplane put on two punt-like floats (though any designer will tell you how great a fallacy that conception really is). A boat seaplane looks like a rather bulgy motor launch with wings. Each type has its advantages and disadvantages, but one cannot lay down the law of superiority, as the particular use for which the aircraft is needed is the deciding factor. Floats for fighting—boats for bombing is not a bad gospel, but like most trite remarks, horribly incomplete. The float seaplane is often awkward and difficult to handle on the water by the pilot, but comparatively easy to handle by a motor boat or waders. The boat seaplane is almost the opposite. In the air the floats are a dead weight and a nuisance. In the air the boat seaplane hull is convenient, but the position of the engine up in the air is a nuisance in several ways. But it has to be away up there because when any seaplane is

rushing through the water getting up speed to get off it throws out almost solid water in a wave, and the rapidly revolving propeller doing perhaps one thousand revs. per minute has to be kept clear of this, or it will be smashed to smithereens.

The boat seaplane presents most of its problems in the hull.

The hull is built much like the hull of any small yacht, with a kind of basket work inside consisting of keel and fore and aft long pieces called stringers and athwartship members called timbers, frames and floors. On this framework is fastened the closely butted planking. In small boats one skin of this, perhaps as thin as 3/16 in., or the thickness of a paper exercise book, in large hulls two or three skins giving a total thickness of perhaps 1/2 in.

In order that the hull shall give the minimum resistance in the air when flying it is necessary for it to be smooth and even in shape—well streamlined as we call it. The best shape for this is a sort of cigar with a rounded nose and pointed tail.

If we were to build our hull in this form it would be lovely in the air, but unfortunately we should never be able to get it there. As we drove it through the water trying to get off we should find the water would cling to its curved sides, suck it down hard and even indeed probably run up its smooth sides and swamp it.

To get over this we have to fit on a special bottom—which is very different from anything we've been accustomed to in ordinary boats. This extra bottom is often outside or stuck on to the hull proper and consists of a flat surface which is usually V'd from the keel and extends from the nose to somewhere about the centre of gravity of the seaplane, at which position it is abruptly stopped off and forms a thwartship step.

The flat surface of the bottom will, you can imagine, help to lift the hull on to the surface of the water, just as the flat surfaces of the wing lift the aircraft up in the air—in fact the planing surface, as it is called—makes the hull “fly” in the water.

When the hull reaches the limit lift that this planing surface can impart to it is riding on the step only—going along very fast—nearly fast enough for the wings to take up the weight and flights to be achieved. The step has also broken the flow of the water round the hull and stopped the clinging and sucking action referred to above. The water resistance has been falling rapidly as the hull began to lift out on to the step; a few more seconds for speeding up and the boat sails up into the air.

You will note in most boats and some floats, too, that there is a second step aft of the main step. Correctly designed this should do nothing in the way of lifting the hull out of the water, it is put there to stop any tendency to pitch fore and aft, or “porpoise”; if the hull rolls forward the planing bottom pushes it back—if it rides back tail down the rear step comes into play and, though small, it is a very efficient water planing surface and kicks the hull up on to an even keel again. The art of knowing how to place this step with regard to any particular form of forward planing bottom and any particular size of boat is one of the sealing wax secrets that has been discovered by painstaking research for years past and indeed is still being explored.

We find these things out by making a model hull about 3 ft. long in wood and towing it along at definite speeds in a great tank like a swimming bath—the William Fronde national tank—at the National Physical Laboratory, Teddington—and cunning folk trained to observe these things deduce us valuable laws and guidance for future use. It is a very, very interesting subject because you cannot calculate much—you've just got to know and then use your judgment.

Boat seaplanes have to be fitted with wing tip floats on the bottom planes to prevent them rolling over sideways when at rest on the water. As soon as they start moving and have attained a speed of about 15 knots, most boat hulls

are laterally stable and do not require the help of the wing tip floats. Perhaps one day we shall be able to dispense with these. At present they are an absolute necessity on the water, but waste weight and resistance in the air.

Let me now tell you why the seaplane is so very important a kind of flying machine. I have told you it is a natural type of aircraft, it is natural both nationally and physically. To begin with there is twice as much water on this cheery old earth as there is land, not counting the thousands of inland lakes of inestimable use to the seaplane in various parts of the world, notably Canada for instance, which is dotted all over with them.

Beneath the seaplane at sea there is always an "aerodrome" in all directions; it is never limited by hedges and clear runs and such like restrictions that beset the land machine. It doesn't matter how much space is wanted to get it off, the space is there.

This means that the size of the seaplane can be only limited by the nature of the materials, etc., from which it is built—a very great and valuable asset for the seaplane.

Thus, seaplanes are generally of larger dimensions than land machines. In the late war we had hundreds of two-engine leviathans (I believe that is the right journalistic word!) of round about seven tons in weight, a few of 10 tons weight, and just now we are experimenting with 15 tons, whilst the designers in this country have well visualised the possibility of boat seaplanes up to 50 tons, and I have seen well-developed designs of two such flying boats.

I say it in no boasting spirit and with full knowledge of all it implies, that Great Britain is ahead of all the rest of the world in seaplane design and construction.

We are an island race, we have to get about over the water and so the seaplane comes naturally to us; we have developed it instinctively as being the type we *must* develop—just as our forefathers developed ships and made the Empire so must we develop seaplanes and keep it. We cannot do without our ships—don't imagine that—but we *can* make some of them fly and so increase their utility. Outlying spots in this vast Empire can be both efficiently patrolled and mothered and helped by a few large boat seaplanes working from a ship or shore base at one quarter the cost or less than the equivalent patrol vessels and crews, etc., and I look forward to the days when the large flying boats will be features of every port.

The boat seaplane, by its ability to be built big, is capable of long distances, say 2,000 miles, with small crews and mails, short distances, say 500 miles, with a number of passengers in complete comfort.

The seaplane is so much faster than anything that moves upon the surface of the waters that its time-saving qualities are self-evident, whilst it is not necessary to strain after record speeds, except so far as such design develops clean lines and consequent low resistance—or high air efficiency and correspondingly better carrying capacity in pounds or people.

One of the bugbears of land flying is the fear of being up after nightfall and having to land in the dark.

Thanks to an ingenious device no such fears need assail the seaplane provided it be clear of shipping. This device is called the Cooper night-landing stick, and it consists of a swinging pole or spar which can be hung down by the pilot over the side of the boat as he glides down towards the water. The top or boat end of this pole is connected on to the tail control of the seaplane.

The pilot glides down to the sea at a reasonably gentle angle—and having all the ocean to land in there is no necessity to make this angle steep—and the "stick" does the rest, for when the seaplane is about 20ft. above the water the lower end of the stick or pole touches the surface of the water and is naturally

swept backwards sharply. The swinging stick then operates the tail control flaps, or elevators as they are called, and the glide is flattened out—the descent checked—and the seaplane, perhaps with one or two more correcting kicks from the stick, settles safely and flatly down on to the water.

What of the men?

The men are bred in England. Clear-headed designers, skilled in all the many sciences that go to create a flying boat, primed with hard experience, versed in the arts and ingenuity that make success. The pilots, clear-eyed, quick-thinking wonder men, half sailors, half flying men, or, to parody Mr. Kipling, "a kind of giddy harumphrodite airman and sailor, too." Brave because it never occurs to them to be otherwise, cool because they are British, excellent because they are the salt of the earth.

A land pilot, I consider, is usually born and sometimes made—a seaplane pilot, like the poet, is born not made; and above them all stands the test pilot with the hands of an angel and the nerves of steel. It has been my honour to know many of them and it is my delight to accord them my admiration in this lecture. It takes a real man to take the first untried experimental aeroplane or seaplane up on its initial flight, knowing little or nothing of what tricks it may have, knowing only how it ought to behave, to put it fearlessly through its paces and return and give the waiting designer the valuable facts of its technical behaviour on which alone it may be improved and future designs conceived.

When we are young we say "Let's pretend"; when we are growing up we say, "I wish I could do so and so"; when we are grown up we say, "I predict"; and let me now have my little castle in the air and try to visualise the seaplane of some years hence—years when you are all members of this Society, and old, old members at that.

The Anglo-Argentine Air Line, running from Southampton to Buenos Aires, via Bordeaux, Lisbon, Canary Islands and Pernambuco and Rio. Tenders, small amphibian or wheeled boats, leave London (the Thames) every ten minutes for Southampton—half an hour's run. The air liner lies in a special dock, her wings, some 100 yards in span (and you who have tried to run it in 11-1/5 secs. know how long that is), tower 40ft. into the air; along the bottom one is a promenade deck fitted with rails, mooring bollards, etc. The passengers arrive from the tenders with personal baggage for two days, the weight of which has been checked in London, and walking along the deck find their way into the capacious hull, where they repair to their compact and ingeniously devised cabins—small but sufficient—on two decks with the dining-room and saloon forward. Above the hull is the sun room, a glass-sided chamber—divided for the smokers, etc.—and commanding an all-round view of the world from the air. Above this and in the top plane is the chart house and pilot captain's quarters. The crew live in the wing tip floats (the size of small yachts) and the steward and cook aft in the hull. The engines are behind the chart house and the vast metal propellers are arranged two out on the wings and maybe a third one forward of the sun room.

At last all is ready to proceed. The passengers are all up in the sun room, the mails are stowed in their parachute bags in the dropping traps in the bottom plane, electric fuel pumps are whirring quietly and the deck house doors are closed. The mate is shouting orders through his megaphone from the bridge on the top plane; the great centre propeller begins to flop round and then purrs away comfortably as the lock gates in front open and the Air Boat "Megalomania" glides out on the top of the tide into Southampton Water and proceeds on the surface at 20 knots clear of all shipping. She turns into the wind, the wing propellers commence to revolve faster and faster. The whole ship seems to sit back to her work. There is at first an ever-increasing smother of spray, which

gradually dies away as the speed increases. At 70 knots we are off Beaulieu and suddenly the water leaves us and the still sense of speed and restful flight comes over the ship as she rises steadily to the purring of her great propellers and shapes her course down Channel on her two days' run to Rio and the hardened travellers settle down to games and books under the watchful eye of the sun room steward.

Am I so very far ahead? I wonder! Maybe it is in the hands of some of you, my friends, to make my dream come true.



CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

DEAR SIR,—There are two points of interest in connection with the Langley machine which appear to have been overlooked in Mr. Griffith Brewer's paper and also in the discussion which followed.

The first point is, that Langley was attempting to fly in 1903 with a machine having a loading of about 13 ounces to the square foot. I do not know whether this is an impossible task or whether it has ever been performed, but it would be interesting to know whether, in addition to attempting to fly, Langley was not trying to make a performance which has never even yet, with all the flying experience of to-day, been accomplished, namely to fly with a loading of less than 1lb. to the sq. ft.

The other point will only be within the knowledge of visitors to the U.S. Museum at Washington. There, in the hall, two models are suspended, one model that of Hargrave, which is labelled "Hargrave Flying Machine. Driven by compressed air engine. Flew 312ft. at Clifton, N.S. Wales, in 1891." This model hangs in a modest little corner shaded by the gallery of the Museum. Out in the open, lighted by the windows above the gallery, is suspended the larger Langley model, labelled as follows:—"Langley Flying Machine. The first successful flight made by a machine heavier than air driven by its own power was made by this steam flying machine on May 6, 1896, at Quantico, Virginia, over the Potomac River, with a steam pressure of 150 pounds."

What I should be interested to know, would be what the word "successful" means on the Langley model. If you omit the word "successful," the label is obviously incorrect, because the Langley model did not make the first flight by a machine heavier than air driven by its own power, because of Hargrave's model which did this five years earlier. There is some subtle difference, therefore, in the word "successful," which distinguishes the Langley model from the Hargrave model, and for the benefit of the general visitors to the Museum it would be well to have some explanation of the Smithsonian definition of the word "successful." Is it the same as the word "substantially," or "practically"? As the well-known judge once said, when he was told that a door was "practically" shut, he knew very well it was open. No doubt the word "successful" refers to the duration of the flight and the size of the machine. It would apparently relate to the duration only, because when the Hammondsport machine was tried at Hammondsport later and flew less than 312ft., it was "successful" according to the official report. What may therefore be successful in a large machine is apparently not successful in a small one. No doubt some of the Smithsonian scientists can help to elucidate the meaning of this elusive word.—Yours truly,

JAMES GUTHRIE.

750, Prospect Avenue, Cleveland, O.

January 5, 1922.

Berlin Lichterfelde,
Marthastr. 5.

To the Editor of the AERONAUTICAL JOURNAL.

Dear Sir,—Many thanks for sending the AERONAUTICAL JOURNAL, the contents of which has found my greatest interest.

As I have always been the fellow worker of my deceased brother in his aeronautical researches, I am well informed about the proceedings in the investiga-

tions of flying. Please permit me to take part in answering the question: "Who is the inventor of the flying machine?"

As Mr. Handley Page quite right mentioned, every invention is based upon the preparatory work of several students. This preparatory work may it be purely scientific or refer to mechanical appliances to introduce science into practical use, can be traced to every invention. It has always been the habit to spend the laurel to the victor in the race to success and I have never declined to call the Brothers Wright as the true inventors of the flying machine.

If Mr. Langley would live now and claimed to be the real inventor I am sure the world would laugh at him, but as far as I am informed he never rose this claim.

His apparatus did not fly because it was not properly constructed, and the novelty in the construction, the vaulted section of the wings, was no invention of Mr. Langley's, but of the Brothers Lilienthal. Mr. Langley got his information about the increased lifting force and favourable direction of the resulting air pressure by the book, "*Der Vogelflug, als Grundlage der fliegekunst*," published 1886 by Otto Lilienthal under my assistance, and by our personal information when he called at us 1895. We showed to him our stock of gliders and my brother made several glides at our experimenting place at Lichterfelde. Myself gave the explanations in English language.

Although the Brothers Wright got also one of our gliders which had been ordered by Mr. Chanute and they made their first experiments with our apparatus, I do not deny to them the glory of inventorship. They have made the first man flying from the ground and with this fact the dispute must stop.

If the claim of the Smithsonian Institution should succeed my brother and myself could just as well be entitled to raise the same claim. Our gliders, when driven forward by a screw propeller, would have been able to fly, but at that time, before 1896, we were not able to secure a motor light and powerful enough for this purpose. We had been dealing with Mr. Benz, of Stuttgart, who built the first explosion motors, but he declined to construct a motor that could suit our demands.

Our investigations and measurements of the air resistance on vaulted planes goes as far back as 1872. They are published in the above-mentioned book. A second edition is published in England, "*Bird Flight*," by myself.

You will see that flying has been made possible not only by the vaulted wings and not only by the light and powerful motor, but by both factors, and the man who brought both means to an harmonic combination is entitled to be called the inventor of the flying machine.

There is no doubt that the Wrights have been these men.

I am, Dear Sir, yours truly,

GUSTAV LILIENTHAL.

You would oblige me to send enclosed letter to Mr. Griffith Brewer, whose address I don't know.—G.L.



OBITUARY.

EDWARD P. FROST, J.P., D.L.

One more link with the past has gone in the death on 26th January of Mr. Edward Purkis Frost, one of the oldest pioneers of aviation. Born in 1842, he early became interested in the subject of flight and his name first appears in the list of members of the Aeronautical Society in 1875. In 1880 he was elected to the Council and became President of the Society in 1908. Among the old "Reports" of the Society his name frequently appears, and in 1883 he read a paper on "Aeronautics, with remarks on a visit to the Aeronautical Exhibition in Paris." In the 23rd Report is another paper by him referring to his experiments on feathers.

As a typical country squire, rather than the scientific engineer, Mr. Frost was ever watching the flight of birds and critically examining their wings. Insects and even winged seeds were also objects of his close study. Living in one of the finest partridge districts in England, Six-Mile Bottom, in Cambridgeshire, he was a keen shot and had every opportunity for studying the flight of these and other birds. The structure of the feather was his special problem. From small models of artificial feathers he evolved larger ones till he made some of 14 feet long, one of which was exhibited at a meeting of the Society in 1891. The main rib being on one side of the central axis, when the feather was beaten downwards, with ever so great an effort it always slipped away to the side, showing the propulsive force of a natural wing beat.

This led him to the construction of a full-sized flying machine of the "ornithopter" or beating-wing type, which took him ten years to build. It was originally supposed to be an exact imitation of a crow, though as eventually carried out it became very different, having supplementary aeroplanes and other features. It had a span of 30 feet to wing tip and was composed of 80 large artificial feathers. It was to be actuated by a steam engine, the whole weight, including engine and boiler, being 650lbs. But great difficulties were experienced with the engine, which did not develop so great a power as was anticipated, and the machine remained for many years merely as a monument of patient endeavour.

In 1902 Mr. Frost started on another series of experiments, in conjunction with Dr. Hutchinson and Mr. D'Esterre. These were described and illustrated in the AERONAUTICAL JOURNAL for July, 1903. The larger model consisted of a pair of wings, 20 feet across, actuated by a 3 h.p. petrol engine. These were mounted on a light steel framework on wheels, and were arranged to flap 100 times a minute.

King Edward, when Prince of Wales, showed much interest in Mr. Frost's experiments, and during his shooting expeditions to the neighbourhood visited the sheds and workshops.

Mr. Frost, among many other interests, made a study of the subject of universal peace, and wrote an interesting book, entitled, "Safeguards for Peace: A Scheme of State Insurance Against War," published in 1905.

To his friends he will ever be remembered as a courteous gentleman of the old school, enthusiastic on his hobbies, and ever ready to assist the cause of aeronautics in an unselfish and retiring manner.



PUBLICATIONS.

The following papers, etc., are published by the Society:—

Transactions.

1. "The Calculation of Stresses in Aeroplane Wing Spars," by Arthur Berry, M.A. 5s. od.
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APRIL, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on Tuesday, March 21st:—

Associate Fellow.—Squadron Leader J. Sowrey, A.F.C.

Students.—G. F. Law, A. E. Woodward Nutt, A. D. Patwardham, E. J. D. Townesend, T. E. Waldeck.

Member.—Captain S. H. Starey.

Foreign Members.—Lt. Commander R. Arisaka, I.J.N., Captain D. Tiselius, R.S.N.

Annual General Meeting.

The Annual General Meeting was held on Tuesday, March 28th. Minutes of the proceedings will be published in the May issue of the Journal.

Lecture.

The remaining lecture of the present Session will take place at 5.30 p.m. on Thursday, April 6th, when M. Louis Bréguet will read a paper on "Aerodynamical Efficiency and the Reduction of Air Transport Costs."

Students' Section.

The following programme has been arranged:—

Friday, April 7th.—Annual Address to Students. Professor L. Bairstow on "Some Aeronautical Problems of the Early Future." 6.45 p.m. in the Society's Library.

Saturday, May 6th.—Visit to de Havilland Aircraft Works. Meet at the Works at 10.0 a.m.

Wednesday, May 31st.—Visit to Royal Aircraft Establishment. Meet at Waterloo at 8.40 a.m. at the Booking Office.

Saturday, June 3rd.—Visit to National Physical Laboratory. Meet at Waterloo at 9.30 a.m.

Any member of the Society is invited to attend Prof. Bairstow's lecture to the Students' Section.

Library.

The following books have been received and placed in the Society's Library:—"Howard" Lectures on Aero Engines, by A. E. L. Chorlton, Royal Society of Arts; Alloys Research Committee's Reports, 1907, 1910 and 1921; "Structural Analysis and Design of Airplanes," Major T. G. Bane; "Deutschlands Krieg in der Luft," by von Hoepfner; "Grundlagen der Flugtechnik," by Dr.-Ing. H. G. Bader; "Notes and Examples on the Theory of Heat and Heat Engines," by John Case; "La Photographie Aérienne," by A. H. Carlier; "Cours pratique d'aviation," by Capitaine Gambier and Lt. de Vaisseau Amet; and "Research in Industry," by A. P. M. Fleming and J. G. Pearce.

Associate Fellowship Examination.

The Council have decided, as a result of representation which has been made to them, to hold the examination for Associate Fellowship in September instead of in April this year, as it has been found that this would be more convenient for the majority of students who desire to sit for the examination, owing to their studies having been delayed by the war. Intending applicants should forward their names to the Secretary not later than July 31st.

W. LOCKWOOD MARSH, *Secretary*.



PROCEEDINGS.

SEVENTH MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held in the Rooms of the Royal Society of Arts, Adelphi, London, on Thursday, January 19th, 1922, the President, Lieutenant-Colonel M. O'Gorman, in the chair, when a paper on "Engine Installation" was read by Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E., M.I.Mech.E., F.R.Aë.S., M.I.Aut.E.

The CHAIRMAN, in announcing the title of the paper, said that Brigadier-General Bagnall-Wild was, he was proud to say, introduced to aeronautics partly through his own instrumentality a good many years ago, and he had also known him for 19 years as a pioneer in the realm of the motor car. Accordingly, there was every reason to suppose that he knew something about engine installation. Also, on behalf of the Society, the Chairman congratulated Brigadier-General Bagnall-Wild as a distinguished Fellow of the Society upon his recent appointment to the distinguished post of Director of Research at the Air Ministry. (Applause.)

Brigadier-General BAGNALL-WILD thanked the members and explained, with regard to his paper, that he had been eight years in the A.I.D., and that it was written from that point of view. Also, it was not an individual or personal paper, but a collection of ideas gleaned from the whole of the staff of the A.I.D., dating back to 1914. He would especially thank Major Bulman, O.B.E., and Captain Warner, both of the A.I.D., for the valuable assistance they had given him in the preparation of the paper.

ENGINE INSTALLATION.

It may be stated definitely that installation as a whole has shown little progress as compared with the development of either the aircraft structure or engine, and that to-day the installation of the engine in a machine presents a wide field for sound engineering design and improvement. On the other hand, failure in some part of the installation is the most prolific cause of forced landings. Statistics taken over a considerable period have shown that of the proportion of forced landings resulting from engine stoppage, seven out of eight are due, not to any actual defect in the engine itself, but to some trivial breakdown in the installation.

Apart, too, from the question of reliability and safety, installation development provides room for considerable economy, not only as regards its actual upkeep and repair, but also from its effect on the easy (or otherwise) removal of the engine from the aircraft for overhaul and replacement purposes. The whole of the time and labour spent either in patching up the details of the installation or removing the engine for overhaul and/or replacement, represents a dead loss in the useful flying time of the machine; a factor of importance not only to the Service in that an increased number of machines is required than would otherwise be necessary to meet given operational requirements, but also for civil aviation, in that the nett earning value of the machine is reduced.

The reasons for this lack in development of the installation are not far to seek. In the earliest days, when engines themselves were utterly unreliable, there was no real incentive to provide a sound system of installation; indeed, the disposal and fitting of petrol and oil pipes, ignition control leads, switches,

etc., were more often than not left to the mechanic engaged on the work to effect with the utmost economy in materials, leading too often to makeshifts of string and electricians' tape.

Throughout the greater part of the war it was usually found that the engines for a certain type of machine were unavoidably many months late in delivery, since the period of development of an aero engine must inevitably be much in excess of that required for the aircraft itself. As a result, it was usually necessary in the end to put in some other type of engine, intended probably for a totally different design of machine and to effect the best possible compromise.

A third factor in the situation has been a universal lack of co-operation and mutual understanding between the engine and aeroplane designer, rendered more complete in that almost without a single exception, the two designers in question were not of the same firm or management. The aeroplane designer, perhaps naturally, concentrated his energies on the aero-dynamical and military requirements of his machine, while the engine designer devoted the whole of his attention to the production of an engine of light weight per horse-power, low fuel and oil consumptions, and improved reliability, both overlooking the fact that unless the one provided the optimum conditions for the other the efficiency of the aircraft as a whole must be reduced and the value of the work of both designers correspondingly depreciated. How many aircraft designers, for instance, set out to ascertain the normal working pressure and temperature of the oiling system on the particular type of engine which they proposed to fit and proceeded further to embody in their aircraft designs the necessary means for the attainment of those desired conditions. It may be contended, perhaps, with equal force by the aircraft designer, that if the maintenance of specific oil and temperature pressures were essential to the well-being of the engine, the necessary oil coolers should have been embodied in and actually delivered with the engine.

The fitting of carburettor air intakes provides a further instance in that with only one or two exceptions engines now actually in use are sent out by the engine constructor without these parts, although the exact form of air intake must obviously have a considerable effect on the carburation and general efficiency of the engine. Practically every type of machine will be found to have a form of air intake peculiar to itself, put on, it would often seem, as an afterthought—as a necessary but unimportant evil. As a result, a special tuning up of the engine in the machine after it has passed its test at the engine constructors is involved, and in addition interchangeability of engines between different types of machines is seriously affected.

It may be said that on this point of air intake design the engine constructor is tied down, in that its various individual types have already been settled by the respective aircraft designers, so that it is too late now to introduce one standard type for each engine without involving structural alterations to the machines, in some cases to a considerable extent. There is no obvious reason, however, why in any future design of engine a standard air intake should not be fitted by the engine maker and definitely adopted for that engine. If that were the case, the aeroplane designer would naturally provide for that particular form of air intake just as he now does for the over-all dimensions of the engine itself and the position of its bearer feet.

These general remarks will perhaps serve to show what, in the author's opinion, have provided the greatest obstacles in obtaining sound installation. Fortunately, this phase in aircraft development is disappearing and improved installations are already the result.

The advent of civil aircraft is, to a large extent, responsible for this improvement, for of stern commercial necessity the aircraft and engine designers have been brought into closer touch with each other's difficulties, and the situation will continue to improve with an increasing appreciation by all concerned that without

thoroughly sound installations no increase in reliability of either the engine or the aircraft structure will avail.

Let us now consider what are the principal features required for the evolution of a sound installation and then discuss how far, in the light of present-day experience, these aims may be realised.

The desiderata of a sound engine installation would appear to be the following:—

- (a) Reliability and simplicity of arrangement of petrol, water and oil systems to ensure maximum engine efficiency.
- (b) Every possible safeguard to be taken against fire risks.
- (c) A high factor of safety in the mounting of the engine itself, together with all accessories and attachments required for its working, not only as regards initial soundness, but also in the individual capacity of the component details for long service.
- (d) Ready accessibility of the complete engine and installation, particularly for those parts which require frequent inspection, such as carburettors, magnetos, petrol pumps, petrol and oil cocks, filters, controls, etc.
- (e) The arrangement of the installation to be such that an absolute minimum of disconnection and displacement is entailed in the removal of the engine. It should be possible to remove an engine for overhaul and to replace it with a serviceable unit in, say, not more than two hours. Indeed, I look forward to the attainment of something approaching the replacement of a locomotive as now effected on long distance "through" train services, so that the aerial passengers or cargo can proceed almost without interruption over considerable distances.
- (f) Arrangements for engine starting to be of a simple and reliable character.

By considering each of the foregoing paragraphs in detail, and applying the results to the installation of a single-engined aircraft, the fundamentals of installation will be fairly well covered. The installation of multi-engined machines, where they differ in principle from single-engined machines, can be dealt with as occasion arises.

Petrol System.

So far four distinct methods have been applied to the supply of petrol to the engines:—

- (1) By situating the whole of the petrol containers above the carburettor and feeding by gravity.
- (2) By air-driven petrol pumps, pumping direct from the main tanks to the engine or via a gravity tank.
- (3) By air pressure raised in the main tanks by air pumps, petrol being forced from the main tanks to the engine direct or via a gravity tank.
- (4) By providing a vacuum apparatus to raise petrol from the main tank to a gravity tank and thence to the engine.

It will be agreed that for reliability and simplicity gravity feed is the ideal, but so far the difficulties, from the aerodynamic point of view, in the situation respectively of the engine and fuel tanks to utilise gravity feed have been considered too great. I sometimes wonder if the simplicity and efficiency of gravity petrol feed have been sufficiently realised by aircraft designers, and whether a satisfactory design could not be evolved if the provision of gravity feed were made a condition of acceptance of the aircraft. Indeed, in view of the comparative unreliability and complexity of other systems, it may eventually be found

necessary by civil companies to specify gravity petrol systems even at a slight expense of aerodynamical efficiency.

A very deep fuselage with the engine placed low in the front and the petrol carried as far back as possible and at the side or the top of fuselage should readily lend itself to the system, since most carburettors will function at a minimum head of 18in.

Obviously, if propellers driven by transmission shafts and gears prove to be successful present difficulties should be much reduced in that the engine may be installed in the bottom of the fuselage or hull, and the petrol carried in the fuselage or hull, or on the wings to provide a gravity feed. In addition, the fuel could be placed at some distance from the engine, thereby greatly reducing fire risks.

The value of gravity petrol systems to multi-engined machines would be greatly enhanced, especially in Service aircraft, for reasons indicated later.

Air pressure systems for Service aircraft were abandoned during the war, owing to extreme vulnerability, in that if one tank or for that matter practically any part of the air supply system gave out or became damaged by gunfire the whole supply failed except for the limited emergency supply usually carried in a gravity tank.

Direct petrol pumping systems then came into use. Slow speed propeller driven plunger pumps were first used on seaplanes; they were fairly reliable in action, but owing to their intermittent delivery they had to be coupled to the engine via a gravity tank, which then became the sole duct to the engine.

High speed propeller-driven centrifugal petrol pumps were next introduced, coupled usually to feed direct to the engine, and in addition, to an emergency gravity tank kept "topped" up and overflowing back to the main tanks, any excess pressure in the system being dealt with by relief valves. Non-return valves prevented the return of petrol from the gravity tanks. In these systems, therefore, the main supply is obtained direct from the pumps with an emergency supply always available from the gravity tanks.

The average speed of these centrifugal pumps is 3,500 r.p.m., and mechanical failure is, unfortunately, still too frequent. To guard against this two pumps are usually fitted. It is inadvisable that these pumps should work with a suction lift, and accordingly they are usually placed below the petrol in the main tanks, which in itself is a disadvantage. Further, it is clear that the duplication of pumps, etc., to attain some measure of reliability adds enormously to the complexity and weight of the system, particularly in multi-engined machines.

Apart from these inherent troubles in petrol systems as a whole, there are also considerable difficulties with details to which I would earnestly direct the attention of all concerned with a view to effecting improvements.

Take petrol pipe lines. Probably petrol pipe lines have been a greater source of trouble from a maintenance point of view than any other part of the aircraft. It is therefore a matter for surprise that until recently no consistent effort has been made to overcome what is universally recognised to be a vital defect, namely, the use of a tubing formed of rubber and canvas for the connection of the main copper piping at frequent intervals to reduce the vibration and consequent concentration of stress in the metal conduits. This material deteriorates very rapidly, particularly if the petrol contains anything approaching the percentage of aromatic content required to obtain maximum engine performance. The changing of all such joints is required in any case every three or four months—on a big machine a lengthy and costly operation.

Two methods have recently been introduced to overcome the difficulties. One is to do away altogether with flexible non-metallic joints and to provide an all-metal rigid connection. It is well known that where pipes have broken in aircraft they normally failed at or near the point of rigid attachment. These rigid

joints, however, were made by the usual brass nipple and union nut method, necessitating a brazing operation, etc. The making of such a joint weakens the pipe at point of concentrated stress, and it was therefore decided to design a rigid joint which eliminated the fitting of a nipple and a brazing operation.

A great advantage of this new joint is that it can be easily dismantled and re-assembled and the whole of it exposed for inspection. After the nuts and collars are placed on the pipe the latter are expanded by a special tool. It is necessary to anneal the pipe before expanding, and it is advisable to anneal again after the operation. It is also important that the two ends of the joint are set in correct alignment before tightening up.

So far this type of joint has stood up very successfully during tests. One machine to which it was fitted throughout was badly crashed, but the joints remained intact and did not leak. Further tests are being conducted with promising results.

The second method of eliminating the rubber and canvas joint is to introduce a new material, manufactured by the Blaisdell's Petroflex Tubing Co., a tubing made up with an inner lining of gut and an outer covering of canvas. It is treated for fire resistance and is armoured outside.

The lining of gut is, of course, non-expansive, so that the pipe ends must be plain, save for a slight rounding off of the edges, making the assembly of the joint a very simple matter. Either a special nut or ordinary pipe clip can be used to secure the tubing to the pipe.

Experience with this material shows promising results and it is now in use both on Service and civil aircraft. It has one considerable advantage in that existing rubber and canvas joints can be readily replaced with this material without other alteration.

Copper has been mainly used for petrol pipe lines and is undoubtedly the best material at present for the job. Aircraft manufacturers have, however, for some time past, mainly on account of the difficulties with joints in copper pipe, been investigating the use of steel for pipe lines. It is to be hoped that improvements in the jointing of copper pipes will proceed, reducing the necessity for any change in material until something more satisfactory than copper can be found.

Slow progress in the evolution of a satisfactory petrol cock has always been due to the difficulty in finding a material capable of withstanding the disintegrating effect of petrol, whilst with metallic materials, no lubricant is effective in counteracting the abrasive action set up by petrol between two metal rubbing surfaces. Messrs. Vickers have designed a cock with a phosphor bronze body and plug of stainless steel, hardened and ground to a very fine surface, which in conjunction with the hardness of the plug reduces the abrasive effect when the cock is operated. A special spring-loaded packing gland prevents leaks and ensures smooth and easy operation. Numbers of these cocks are in satisfactory use on Service and civil machines to-day.

Engine Mounting.

An engine mounting must have a high factor of strength above the maximum torque it is likely to receive, and be sufficiently rigid in all directions to withstand intermittent and concentrated loading without distortion sufficient to stress unduly the engine crankcase. Bearers, in fact the whole mounting, should preferably be produced in metal (steel) which further overcomes all the difficulties arising from the shrinkage and deterioration which take place with wood; the fire danger is also reduced and a longer life ensured to the mounting.

Messrs. Rolls-Royce have introduced into the "Condor" engine an in-

teresting development comprising a bush which serves as a sort of universal joint. This bush, which is first fitted to the engine bearer tubes, has a spherical portion over which the actual engine feet are bolted. A close working fit obtains between the bush and the engine foot, so that should the bearers for any reason be thrown out of alignment or distorted temporarily by landing shocks, etc., the undue stressing of the crankcase which would occur if the feet were rigidly fixed, is obviated.

Another feature of the same system is that provision is made for any longitudinal expansion of the crankcase by leaving the two bushes for the rear engine feet free to slide along the bearer tube, while the two front bushes remain fixed to the bearers.

Engine Controls.

There is an extraordinary and, in my view, an inexplicable lack of uniformity in the type of engine controls fitted to various aircraft. The only respect in which all seem to agree is in the direction of operation, viz., a forward or upward movement of the control to secure the "open" position.

Some controls are well designed in detail and in their general lay-out; most are comparatively primitive. Positive acting rod type of control is, so far, the most satisfactory, especially when the details of levers, brackets and bearings are well designed and made. Cable controls, although convenient to instal, especially on multi-engined machines, are unsatisfactory in several respects, in that frequent adjustment is required to correct the stretch and maintain synchronisation, while in addition a wire may become frayed in an inaccessible place and remain unseen until it breaks.

Controls should all be clearly marked to indicate their purpose and direction of operation, and even then the levers should be quite distinctive, either by position or shape, so that the operator can recognise them immediately in cases of emergency by touch while wearing flying gloves.

It is usual to inter-connect the throttle and altitude controls and in some instances the ignition is also inter-connected with the throttle, so that although each control can be operated independently, the act of closing the throttle will also close altitude and retard ignition.

Oil Systems.

These are usually of a simple character. A tank carrying sufficient oil is situated above the engine pump. It is important to fix the tanks above the pump to obviate any risk from the pump failing to lift correctly owing to suction leaks, etc.

Adequate arrangements are required to ensure the oil maintenance of the temperature as specified by the engine makers. To this end an oil temperature recording device should be permanently installed in at least the first machine of a type, so that temperatures can be taken during type tests.

Water Systems.

As this paper deals only with installation, it is not proposed to deal with the actual details of radiator manufacture.

Honeycomb radiators with tube blocks made from tubes 10 m.m. \times 120 m.m. are most commonly used.

To determine originally the size of a radiator for any particular machine is a matter of considerable difficulty owing to the absence of sufficient reliable data

on the subject, and also the many variables encountered, *i.e.*, difference between summer and winter conditions, extent of cowling, position of radiator, difference of temperature with altitude, size of pipes, etc.

As a result, however, of numerous tests carried out, an average figure which serves as the basis for calculation has been arrived at for most of these variables, *viz.* :—

Atmospheric temperature is taken to be that of the average English summer conditions, *viz.*, 23°C., and a decrease in temperature with altitude as shown in following table :—

TEMPERATURE CONDITIONS.

Altitude in feet.	ENGLISH SUMMER.		
	Temp. Fall. °C.	A Atmos. Temp. (Assumed °C.).	B Boiling Point. (Approx. °C.).
0	0	23	100
2000	3	20	98
4000	6.4	16.6	96
6000	9.4	13.6	94
8000	13	10	92
10000	16.4	6.6	89.6

Extent of cowling is a much more difficult matter. With an engine absolutely exposed to an air speed of 60 m.p.h., between 44 per cent. and 55 per cent. of the water jacket heat can be dissipated by the engine itself, whereas if an engine is completely or partially "cowled" the whole or a proportion of that temperature has to be dealt with by the radiator. For efficient cooling it has been determined that the "exposed" engine would require a rate of water circulation per 100 h.p. of 11 g.p.m., whilst the "cowled" engine would require 22 g.p.m. Obviously engine water pumps cannot be designed to suit each of these conditions, so that a minimum of 15 g.p.m. per 100 h.p. is now specified for the rate of flow through all radiators for Service aircraft.

There are, of course, other important factors entering into this subject which cannot be gone into in this paper. Sufficient, however, has been said to indicate the difficulties attendant on aircraft radiator design; suffice it to say that this question provides probably the most effective ground for contention to-day. On the other hand, good average results are now being obtained with radiators on new aircraft, due probably to a tendency to err on the safe side by having large radiators and controlling the temperature by means of shutters to reduce at will the amount of radiator surface exposed.

All radiators should be tested for flow and capability to withstand pressure. Flow tests assist also in the detection of any internal obstructions in the radiator. This test is taken with water flowing through the radiator from a constant head of 7ft. (measured from the radiator inlet), the rate of flow being measured against time into a calibrated vessel placed at the radiator outlet.

Pressure tests are taken by filling the radiator with water and subjecting it to a head equivalent to 6lbs. per sq. inch, also measured at the radiator inlet, the pressure being held for ten minutes without leaking.

Fire Prevention.

Apart from the disposition of the petrol already dealt with, there are other safeguards against fire risks that require to be taken in the engine installations. This important subject has been considered by the Fire Preventions Committee.

Their recommendations, recently published and endorsed by the Air Ministry, are now made a condition of manufacture in all new Service aircraft. A summary may be made as follows:—

- (1) The engine should be isolated from the remainder of the aircraft by a light sheet-metal bulkhead lined with asbestos, in which provision is made for close fitting bushes to take care of any such controls, etc., which must of necessity pierce the bulkheads, and to prevent the passage of flames from the other side.
- (2) To construct the whole of the engine mounting and the remainder of the structure in the immediate vicinity of the engine of fire-resisting material.
- (3) To eliminate all rubber flexible joints and soft soldered joints in the petrol pipe lines on the engine side of the bulkhead.
- (4) To ensure that all carburettor air intakes are taken outboard and exposed to the air stream so that any flames from backfires may be speedily extinguished. This position may not be the optimum in all cases from the engine point of view, but in this instance any slight disadvantage is outweighed by the consideration of fire risk.
- (5) All exhaust manifolds to be taken outboard and exposed to the air stream and right away from the air intakes, any joints necessary to the exhaust system to be so constructed as to be flame-proof.
- (6) All petrol and oil to be carried at the greatest possible distance from the engine.
- (7) Induction systems to be designed and tested at pressures considerably in excess of any to which they are likely to be submitted in irregular running.

Accessibility.

It is obvious that if a part of an aircraft engine or installation requiring frequent maintenance attention is placed in an inaccessible position, the supervision necessary to ensure that such parts actually receive this attention must be increased, and in any case the chances are that the work will be inferior. Despite this fact, it is astonishing to note the usual inaccessibility not only of the parts but of the engine as a whole in many aircraft, particularly seaplanes.

An engine should be completely accessible with a minimum of dismantling of cowling, etc. On seaplanes, where the engine extends beyond the planes and overhangs the water, it is with considerable risk that any work can be done to the engine whilst afloat. For such cases it should be possible to provide, as standard equipment with the machine or as a fixture, a light folding staging, which could be suspended from the engine mounting or other convenient place.

In instances where it is necessary to stand on the planes to gain access to the engines, ample surface specially stiffened up to permit of walking, should be provided all round the engine. In some instances a tread plate will be provided here and there. It cannot be expected that a mechanic can do his work properly under such conditions, when he is in fear of damaging the planes if he moves.

An ample inspection cover or a piece of cowling, easily dismantled and large enough for easy access to the parts concerned, should be provided near such parts as carburettors, magnetos, petrol and oil filters, etc.

Cowling fasteners should be secure, but quick and easy to release.

All joints, bearings, levers, etc., in the engine control system should be easy of access for inspection, lubrication and adjustment.

It should be a comparatively easy operation to remove an engine bodily from the machine. This is a difficult operation on multi-engined machines with engine between the planes, and in such other cases where lifting apparatus cannot be

mounted directly over the engine. In these cases it would be a great advantage to the user if the designer took this matter into consideration in the early stages of his design. It might then have been possible to design an apparatus for inclusion in the ground equipment of the machine consisting, for example, of an extension of the engine bearers supported at the outer end from the ground on to which the engine could be drawn by a winding gear until it is far enough out to be picked up by a lifting gear. Some such apparatus would be invaluable when engine removal in the field is necessary.

Engine Starting and the Ignition System.

Arrangements in use for starting engines are varied:—

- (a) The old and dangerous method of swinging the propeller by hand.
- (b) A hand turning gear fitted to the engine, operated in conjunction with a hand turning magneto.
- (c) Electric motor to turn the engine, in conjunction with a hand-starting magneto.
- (d) The external motor-driven starter as represented by the Hucks starter, whereby a shaft driven by a car or lorry engine is made to engage by a dog or spider coupling with the airscrew shaft.

Of these, the first method is dangerous to the operator and is rapidly going out of use except for small rotary engines; in fact, it is not practicable to start the majority of the high-powered engines in use to-day by this means.

With methods (a), (b) and (c) "doping" is adopted before trying to start the engine, this consisting of pumping petrol or a petrol air mixture directly into the induction pipes. The engine is then rotated a few revolutions with the switches off until the "dope" has become distributed to the cylinders. Whilst it is still turning a hand-starting magneto is operated. This is connected to the sparking plugs via the engine magneto. A central terminal in the engine magneto distributor, to which the starting magneto is connected, is in turn connected to a metal point fixed in the distributor rotar at a point so that it trails at 30° behind the ordinary distributor brush. The trailing point being fixed in this position, firing from the hand-starting magneto occurs late at the sparking plug, so that there is no danger from backfires either to the operator turning the hand gear or to the electric motor, as the case may be.

It is the usual practice to fix the starting magneto and switch near the engine so that the operator starting the engine has them under his control. This arrangement appears to work well, provided that every precaution is taken to keep "off" the engine switches until the actual starting moment.

Method (d), *i.e.*, the employment of a Hucks starter, is undoubtedly efficient at terminal aerodromes where a large number of machines are to be started at different times. It is obviously impracticable, however, for general use and can only be regarded as an isolated expedient.

It is my view, therefore, that in future we must concentrate on the auxiliary engine starter, with which promising results are already in sight. Briefly, the system now in use consists of a small air-cooled two-cylinder unit, one cylinder serving only as a pump and connected by a distributor valve to each of the main engine cylinders in turn. The pressure developed is sufficient within a few seconds to start up the auxiliary engine and to turn the main engine, filling the cylinders at the same time with a suitable explosive mixture, the auxiliary engine pumping cylinder being fed from the small engine carburettor.

DISCUSSION.

Mr. F. HANDLEY-PAGE, who, at the request of the Chairman, opened the discussion, said that he felt the paper was a very solid contribution to engineering and aeronautical knowledge, and for that the Society was greatly indebted to the Author. Most of the difficulties with which those concerned with civil aviation had to contend were due to engine installation, and a good deal of them would have been avoided earlier had there been the closer co-operation between the engine designer and the aeronautical engineer of which the author had spoken. In the days of the war that was extremely difficult. He remembered his firm were engaged in making aircraft during the war, and Messrs. Rolls-Royce were making engines, but his firm were not allowed under any circumstances to communicate with Messrs. Rolls-Royce. They were both engaged on a job so secret and special, each for himself, that co-operation was impossible. He was speaking of the earlier days of the war, and under those conditions it was very difficult to impress upon an engine manufacturer what an aircraft designer wanted.

He had always found that the engine was the bugbear of the aircraft designer. It must be put at such a height that the propeller would clear the ground, and that, unfortunately, generally did away with the possibility of having gravity feed for the whole petrol system. That could be minimised to a certain extent by putting the carburettors lower down, but if they could have an engine with cylinders upside down—that is, projecting downwards instead of upwards as now—carburettors would be lower down, radiator lower down. With such an arrangement, quite apart from reducing petrol and water difficulties, it would give a very much better view for the pilot. From a civil aviation point of view—an operational point of view—when one saw a picture of a multi-engine installation, as illustrated by the lecturer, one was rather terrified at the expense and the difficulty of keeping it in operation, and it made one feel that an aeronautical Geddes committee was necessary to deal with it before one could operate it with any feeling of commercial success. The ideal arrangement would seem to be that in which they had an air-cooled engine, with the petrol tank sufficiently high above it so that it would feed direct on to the carburettor, and the pilot sitting close beside the engine so that all controls were at hand. Invariably he found that the breakdowns that occurred were due to the engine installation system. He again thanked the Author for his paper, which was the most interesting, from a practical point of view, that the Society had listened to for a long time.

Captain WILKINSON said he took it to be agreed by most people that the bulk of the trouble in an aeroplane was due to the engine installation. The engine being the bugbear of the designer of aircraft, the aeroplane installation was the bugbear of the engine designer, so that if the aeroplane and engine designers could get together and agree on a number of points at which the engine could be best attached to the aeroplane, to attach controls, petrol pipes, ignition wires, and so on, it would be possible to have one, two or perhaps three different types of installation for a given engine to cover all types of aeroplane. The engine builder could then put a large amount of the installation into his engine unit, so that a lot of the aeroplane designer's trouble would be eliminated and taken over by the engine builder.

Major-General Sir SEFTON BRANCKER first congratulated the Air Minister on his selection of Brigadier-General Bagnall-Wild for the appointment of Director of Research, and he paid a tribute to the splendid work done for aviation by General Bagnall-Wild from the first inception of the A.I.D. in 1913.

General Brancker said that he wanted to stir up the engine makers. He considered it perfectly ridiculous that at this stage in the development of aviation we should still be flying about carrying several gallons of water and an intricate cooling system which was eternally giving trouble; the water was always either freezing or boiling when it was least wanted to, and the system was a constant source of forced landings. He knew that the experts would contend that water-cooled engines effected a saving in fuel, but personally he was all for the air-cooled engine, and he felt that sufficient energy had not been devoted to the problem of reducing the fuel consumption of the air-cooled engine. For long journeys no doubt the water-cooled engine was the most economical for fuel consumption, but for a trip of two or three hours, which he considered the proper length of a stage in a heavier-than-air craft, he believed that the fuel consumption of an air-cooled engine could be reduced sufficiently to compensate amply any increase of the weight of fuel involved thereby, and so get rid of the various weaknesses of radiators, lengthy water-piping, and so on. In his recollection, the engine which ran best in the East was the old R.A.F.4, which went round like a clock whether the temperature was 120° in the shade or freezing hard; it was only necessary to alter slightly the jet, according to the season of the year.

The lecturer had made a novel suggestion; he had said that he thought at the end of each stage in an air route the engine should be changed instead of the passengers and cargo. This appeared to General Brancker to be a most excellent idea, but instead of two hours mentioned as the time necessary for the change by the lecturer, he thought it ought to take about ten minutes. In such a system the introduction of an air-cooled engine would help a good deal.

About three years ago, Captain de Haviland and Captain Wilkinson between them had evolved a method of fitting an air-cooled engine by which it could be removed from the aeroplane with very little trouble. It was merely necessary to undo four bolts, disconnect the pipes and controls, and remove the whole of the engine unit. He felt sure that if engineers would only devote their brains to the evolution of this sort of installation, the change could be effected in ten minutes.

He thought that the Germans had been always rather ahead of us in installation; their installations during the war possessed a sort of brutal simplicity which we had never attained; and he believed that to-day the Fokker, which is flying between Amsterdam and London, was every bit as good, if not better, than anything we had produced in our latest machines in the way of installation.

Another very important item was the question of self-starting. He was just back from the East, and there two-seater machines were not allowed to fly alone over the desert, one reason being that at least four people were necessary to start a big water-cooled engine. This was all wrong; an engine should be started by one man, and he felt that here again our technical brains had not been applied with sufficient energy to developing a really dependable self-starter. In the East again, he had been very much impressed with the vital necessity of steel or copper, or some metal for petrol connections; the deterioration of rubber in the heat was the cause of many forced landings. To-day, in designing the details of installation, it was absolutely necessary to obtain simplicity and strength, even though a certain amount of extra weight was involved thereby. The loss of carrying power involved by this extra weight would be amply repaid by the saving in time, in labour, and in the salvage of forced landings.

Group Captain BRIGGS said he felt that closer co-operation between aircraft and engine designers would probably produce one of the best solutions of the troubles they all had to face. The lecturer had not mentioned exhaust manifolds. A great deal of trouble was experienced with these, and he believed it was in some measure due to the fact that the engine constructors made some parts thereof and provided for attachment, whilst the aircraft constructors made the remainder. In this instance co-operation would be an advantage. Some

simplification in petrol systems might probably result if engine designers were to adopt some reliable type of mechanical engine-driven pump and thereby dispense with wind-driven pumps and their attendant complications.

Lieut.-Colonel HECKSTALL SMITH said that as the information given in the lecture was of the greatest possible value, he would like to know whether such information was generally obtainable and whether any published data existed on breakdowns and accidents and the findings as to causes leading up to them.

Squadron-Leader MILEY said that the engine designer and the aircraft designer had blamed each other in the past for anything that went wrong, and now that they had discovered there was something lying between them, they both said that the trouble was due to the installation and the many miscellaneous parts that were necessary to enable the engine to run. It seemed, therefore, that there was room for some enterprising gentleman to start a new industry for the development of engine accessories, filters, pumps, pipe joints, and all those accessories which required so much improvement. The author had said that engines were very inaccessible in seaplanes. As a matter of fact, a great many seaplanes were in service in which engines were uncowed, and were quite easily accessible by standing on the lower plane. There were hundreds of these machines in service, and there were very few troubles on account of engine installation, in spite of the fact that the question of installing the petrol system was very much more difficult than was usually the case in the ordinary aeroplane. This was due to the fact that in seaplanes of the boat type it was necessary to carry the bulk of petrol very low in relation to the engine.

Major H. E. WIMPERIS agreed that installation had been one of the greatest difficulties in aircraft in the last six or seven years, and there was still room for improvement. The lecturer stated that he had put forward a departmental view as Director of Aircraft Inspection, but he was doing far more, because he had had a long personal experience of internal combustion engines of many kinds. Doubtless at the Air Conference in the following month we should learn the author's programme as Director of Research at the Air Ministry. He had rightly laid stress on the importance of fire prevention, and he (Major Wimperis) always desired that when that subject was mentioned, a tribute should be paid to the splendid work of Major Norman in that direction; he paid tribute, not only to Major Norman's technical knowledge, but to his marvellous courage in being willing to hazard the experiment of setting his engine alight in the air. Speaking of the gravity feed for petrol, he was a little surprised that the author had suggested placing the petrol tank some distance horizontally from the engine, because one could not help wondering how, in some fast-climbing machines, the gravity feed would still be able to give the requisite 18 inches of head. With regard to the table of temperature conditions in the paper, he thought it would be wiser, in considering a matter of that kind, not to take average temperatures, but the extremes. There was one point which might conceivably be new, even to the lecturer, with regard to engine installation, and that was the weird effect sometimes produced by the hand magneto on the pilot's compass. If the hand magneto happened to be left in a position in which the armature was across the poles on one occasion, and at right angles to the poles on another, the compass deviation changed appreciably. This might give a misleading result if the compass installation was, either by accident or any other cause, placed in the neighbourhood of the starting magneto.

Captain BURGOINE amplified the information given in the paper with regard to starting gears. Taking an engine of 500-600 h.p., it might be said that the hand-turning gear would weigh about 15 to 20 lbs., the electric-turning gear about 35 to 45 lbs., plus not less than 45 lbs. for the battery, whereas the R.A.E. starter engine described in the paper would weigh about 45 lbs. complete with accessories fitted on the engine. One starter could be used to start any number of main engines; that would weigh about 40 lbs.; and there would be an additional

weight of 5 or 6 lbs. for each main engine. The Hucks starter was very useful, but was not always available. With regard to ignition wiring, it was suggested in the paper that wires should be painted with distinctive colours. The author had seemed to have forgotten that the standard specification called for a colouring scheme; the colour for the ignition system was blue, and nothing but blue must be used for ignition leads. With regard to a gravity tank above the engine, he could not imagine a more dangerous installation than one shown in the screen.

Major BUCHANAN, speaking of the co-operation of engine and aircraft designers, said that the question was one of extreme difficulty, because, as mentioned by Mr. Handley Page, they had hitherto lived in watertight compartments. Even at the present time they were using engines in the Service which it was practically impossible to instal in such a way as to make every part definitely accessible. Their principal troubles were in connection with the water and petrol systems. With regard to a simple petrol system, it was quite possible, and no doubt practicable, in civil aviation to use a standard gravity petrol system. On Service machines, on the other hand, the problem was one of considerable difficulty, and even if it were possible, there were very serious differences of opinion as to whether or not it was advisable. Experience during the war had led pilots to the opinion that it was very unwise to put all their eggs in one basket, or all their petrol in one tank, and for that reason designers at that time adopted the practice of splitting up the petrol capacity in the aeroplane. That, naturally, led to complications of the petrol system. With regard to Captain Burgoine's remarks as to the petrol system, he would like to point out that the gravity tanks in that particular aircraft were carefully kept in airtight compartments so that there was no danger, except in a very bad crash, of the tanks getting anywhere near the engine. With regard to the cooling systems at the present time, there is a great deal of difference of opinion, and further, the requirements of civil aircraft were entirely different from those required for service. For instance, a Service aeroplane was required to take off the ground on the hottest day in summer and climb at its greatest climbing rate, but no such condition was imposed upon civil aeroplanes. The civil aircraft also had an advantage with regard to the fireproof bulkhead. In the Service aircraft there were such things as guns, ammunition boxes, schutes, compasses, and things of that sort, and in such cases a fireproof bulkhead would have to be of very small dimensions. He joined with Sir Sefton Brancker in maligning the water-cooled engine.

The CHAIRMAN said he was glad to hear the old air-cooled *v.* water-cooled engine discussion being revived by the engineers represented at the meeting that evening. It was a stimulating subject, and if he had at one time been responsible for some developments on the air-cooled side, that did not preclude him from holding the balance impartially and welcoming the winning champion. As regards details of installation, he did not know why the author had eliminated the suggestion of aluminium pipes. Would General Bagnall-Wild speak on this? The goldbeaters' skin joint seemed to promise well, but more as a temporary makeshift during the period of popularising the solid joint, which he believed was a better solution and when standardised would be cheap enough. From a fire point of view, everybody had been impressed by the accident to R.38 as to the effect of having petrol pipes near electric leads, when both might be broken by a crash, the broken pipes providing the petrol and the broken leads providing at the same place the spark due to interrupting a live circuit. One would like to see no accumulators used on an aeroplane. That might be difficult to ask for, in view of the sundries which the author had alluded to; but they were generally more likely to cause fire than anything else on the plane, except, possibly, the exhaust pipe. If they could get engines, no part of which were to be at a higher temperature than 330°C., fire from the exhaust pipe would be eliminated, and that was about half the risk. If they could make sure that an electric spark would

not occur just in the petrol vapour, he believed the other half would be eliminated and fire risk would be swept away from among the apprehensions of the passengers. He was pleased to feel that the members present had been really interested and moved to take part in the discussion initiated by the stimulating paper by Brigadier-General Bagnall-Wild. He called upon the author to reply to the discussion.

Brigadier-General BAGNALL-WILD, replying to the discussion, thanked the members for their remarks with regard to the paper, and expressed his gratification that the speakers in the discussion had been able to give him so much meat for thought. They had not put many questions to him; in fact, they had given a lot of interesting facts which did not need answering. There was only one question he need deal with, and that was the one put by the President, as to why he had not added aluminium as one of the materials for petrol pipe lines. The reason was because he was thinking, not only of land machines, but also of seaplanes, and in a machine at sea the use of aluminium presented some little difficulty.

At the conclusion of the discussion a hearty vote of thanks was accorded the author for his paper.

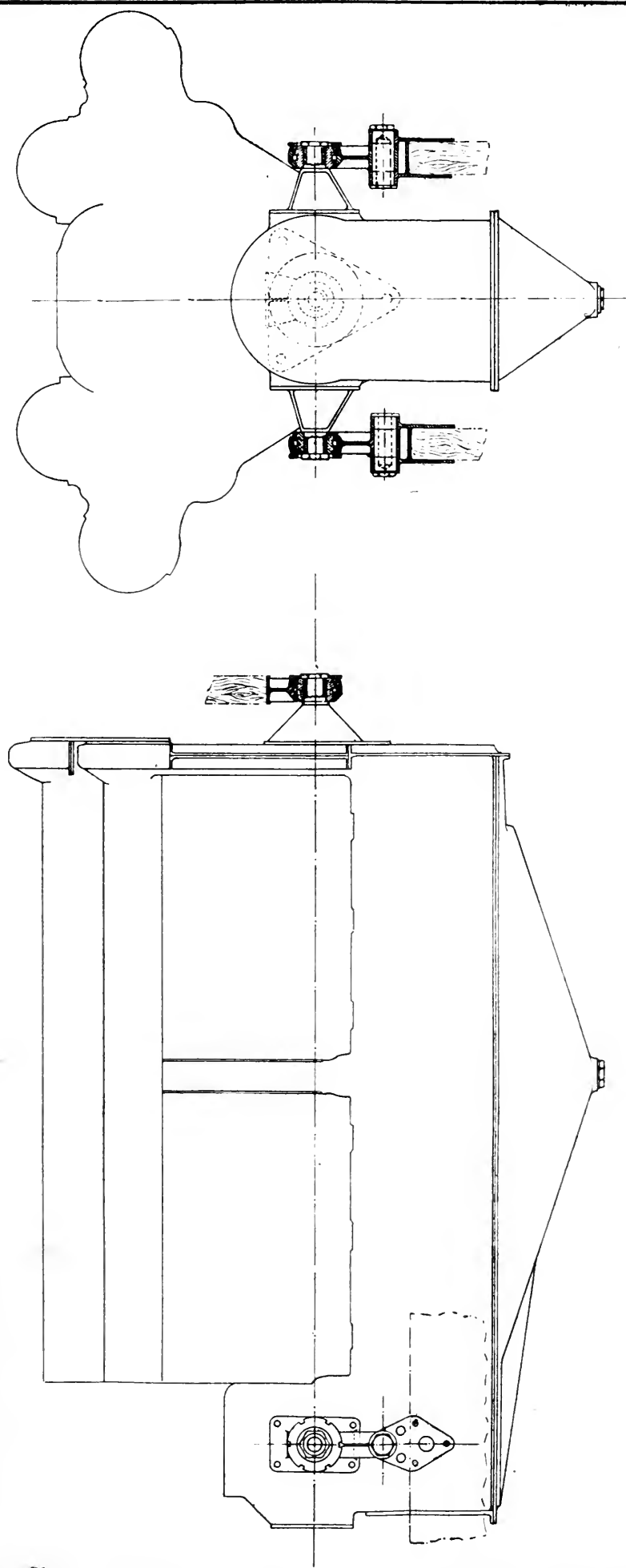
Communicated by Mr. L. COATALEN: Having regard to the remarks of Brigadier-General Bagnall-Wild on engine mounting, I think a form of mounting I have developed for aero engines will be of interest. This is really a natural development of the mounting I have used for many years for racing cars, where it is, of course, very necessary that the transmission and motor is not subjected to undue stress owing to the distortion of the frame of the vehicle in service at high speeds. Briefly, as applied to aero engines, my system may be described thus :—

The portion of the engine crank case at the propeller end, and as near the propeller as possible, is provided with two horizontal trunnions, one on each side, and on the same axis, which is horizontal. These trunnions, which are bolted on to the crank case by flanges so as to distribute the load on the aluminium of the crank case, are spherical in form and fit into short vertical links, themselves carried by and turning on horizontal pins provided on the fuselage, preferably in way of the front cross member or bracing. These links are short and rigid, and are provided at one end with spherical bushings to take the trunnions and at the lower end with parallel bushes for the supporting pins. The other end of the engine is carried by one spherical trunnion as nearly as possible on the axis of the thrust of the propeller, which is fitted to a split spherical bracket rigidly mounted on the fuselage. There are two very important points to which I should like to call your particular attention *re* this mounting :—

- (1) This is absolutely flexible whilst retaining those properties necessary for taking the torque and transmitting the thrust.
- (2) It allows of quick dismounting and replacement of the engine.

The former is obtained by the three-point suspensions adopted combined with the link movements, which allow a longitudinal movement of any one point in relation to any other, and further it allows of the more common distortion of the fuselage in a rotary direction about its longitudinal axis, but at the same time by means of the two propeller end trunnions takes care of the full torque of the engine. Further, the position of the trunnions at the propeller end of the engine definitely locates the point of application of this torque, which allows of a more economical design of fuselage.

(2) The attachment of the motor to the fuselage by three points only naturally permits of a more rapid execution of the mounting and dismounting of a motor, whilst the design of mounting with links, etc., as described, avoids all necessity for lining up or bedding, etc.



APPLICATION OF 3 POINT SUSPENSION TO AEROPLANE ENGINES

22.2.22
1922

The type of mounting referred to by the lecturer is apparently a 4-point mounting, to which any subsequent distortion of the fuselage would impose considerable stress on the engine crank case although the supports had been accurately lined up before mounting the motor, or alternatively, if the design of the fuselage is sufficiently flexible to avoid these stresses, the engine crank case is then subjected to the very serious stresses occasioned by landing, etc.

In addition to the above, an important point is that with the mounting described above, one cannot ensure that the torque is not transmitted through the crank case, as is the case with the more common form of mounting, owing to the deflection of the fuselage. It is practically impossible to design a fuselage so rigid that a certain amount of deflection does not take place, and it will be readily seen with this type of mounting the deflection of the fuselage does not impose any additional torsional stress on the crank case.



SPECIAL LIGHT WEIGHT AERO ENGINE.

A Lecture delivered by

MR. A. E. L. CHORLTON, C.B.E., M.INST.C.E., M.I.MECH.E., M.I.E.E., A.F.R.A.E.S.,

Before the Scottish Branch on February 27th, 1922.

The high performance engine, whether military or commercial, is essentially the light one.

The motor which made flying possible was an internal combustion engine, and the basic reason of its success was the direct use of an easily volatile fuel of high heat value, namely, *petrol*.

The first engine developed to use this fuel was that of Daimler, and all motor-car, boat and aviation engines have sprung from this engine.

In order to more readily have in mind our problem, we can with advantage briefly run through the main aero engines so far constructed with the progressive results of tests.

The engine of Gottlieb Daimler is illustrated by Slide No. 1.* It had automatic inlet valves and exhaust governing, the latter being a point to be noted.

The next slide shows the engine of the Wright Brothers. This engine weighed 8.75 lbs. per B.H.P. inclusive; the most successful engine of to-day weighs under 3 lbs. inclusive.

A number of types then arose, such as the vee, fan, Y, fixed radial and rotary. The following engines illustrate these types:—V., Antoinette; Fan, Anzani; Y, Anzani; Fixed Radial, Salmson; Rotary, 80 Gnome.

The Gnome was at that time the engine most in favour, and as is well known, the Y type Anzani was used by Bleriot in the first cross-Channel flight.

Water-cooled engines were developed from motor-car practice, whilst other designs purely for aero work were in the main cooled direct by air. Thus we have many types and two systems. The various types are indicated in diagrammatic form by the next slide. To illustrate these types, the following figures may be noted.

The more important particulars of engines available in 1910 are given in Table I.,† and the engines which took part in the German trials of 1913 are shown in Table II.

Those entered for the British War Office competition in 1914 are given in Table III.

A number of typical engines are grouped and compared with similar piston speed and cylinder pressure in Table IV.

As I have indicated, the object of this lecture is to emphasise the importance of the light-weight engine as the line to be adopted for experimental work for future progress.

Let us consider the effect of the weight of the engine on the carrying capacity of a given machine. It will, of course, be obvious that for short flights, where little fuel has to be carried and the weight of fuel is small relatively to the

* These photographs are not printed.—Ed.

† Printed at end of Lecture.—Ed.

weight of the engine, the use of an engine of low weight per horse-power is of fundamental importance and economy is comparatively unimportant. It is also obvious that for very long flights where the weight of fuel to be carried becomes large relatively to the engine weight, low weight of engine is of less importance than economy of fuel and oil consumption. This is very clearly shown by the curves. The abscissæ represent hours run, and the ordinates weight of engine and fuel per horse-power in lbs. The performances of different engines are shown, and the heavier early German engines are compared with the light Gnome engine. It will be seen that for runs of anything over three hours the average German engine has the advantage, while below three hours' run the light engine gives an undoubted saving in weight and consequent greater carrying capacity, and would therefore seem a better commercial proposition.

As an example of the commercial importance of a low-weight engine we may consider a flight of $2\frac{1}{2}$ hours, such as that required in the Paris service, which may fairly be taken as typical of the length of stage which will be required in commercial aviation. This length of flight would seem to be the most usual in charge of a single pilot. The following, though not quite up to date as regards fares, is very interesting.

Assuming power units of 500 B.H.P. with weights per B.H.P. 1.5, 2.5, and 3.5 lbs. with fuel and oil consumptions of 0.6, 0.5, and 0.45 lbs. respectively, the weight of power unit and fuel in the three cases would be:—

- (a) 1,500 lbs.
- (b) 1,875 lbs.
- (c) 2,313 lbs.

With the lightest engine (a), therefore, the saving in weight would be 812 lbs., equivalent to five passengers, and with the medium-weight engine 437 lbs., equivalent to three passengers.

The earnings for fifty London-Paris flights at ten guineas per passenger are given in Table V.

It will be seen from this table that the total net earnings in the case of the lightest engine will be £4,125; in the case of the medium engine £3,304 3s. 4d.; and in the case of the heavy engine £1,833 7s.

The earnings for a given carrying capacity, it will be noted, are very large in proportion to any fuel costs likely to be incurred even in the most wasteful of engines as regards consumption.

In this calculation no account has been taken of the initial cost, as this is independent of type and with greater development may well be in favour of the lighter engine.

The provision and maintenance of a given number of engines in working order is allowed for in the renewals and replacement item. These figures very clearly show that for flights such as those required on the London-Paris services, light weight per H.P. is of the first importance.

It has been assumed that the consumption in the light-weight engine is very much greater than that in the heavier engine. With further development of the lighter types this is by no means necessary, and improvements in fuel consumption would obviously increase the balance in favour of light weight.

In this service it is shown how it is the light-weight engine that is the commercial one, and it must be our object to design such and make it fully reliable.

It is rather strange that this view is only now coming to be fully appreciated, for immediately after the war all that we heard was let us have strong and reliable engines, the weight is not so important.

Let us now consider the possibility of reduction in weight from the information available to-day.

We may now consider the question under three heads:—

1. Thermodynamical.
2. Mechanical.
3. Metallurgical.

Dealing first with thermodynamical considerations, up to the present aero engines work almost universally on the four-stroke constant volume cycle with equal expansion and compression, and any departures which have been made from this cycle must be regarded as purely experimental. The power developed by any given cylinder depends on the volumetric efficiency; large valve area and efficient cooling are the governing factors.

There is very little gain to be expected in this direction, though a mean effective pressure of 130 lbs. per square inch has been exceeded, and this figure has been used in our review.

By means of supercharging, weight reduction is more hopeful, particularly if done by fluid pressure alone.

Clerk's supercompression engine is shown by the next slide. The two diagrams on the next figure indicate the increase in the mean effective pressure he obtained by supercharging. A fluid compression method, in which the exhaust pressure in one cylinder is blown through a cooler into another cylinder at the phase of its cycle at which the extra charge is required, is shown at Slide 30.

Some additional cooling will be required on the main cylinder though flame-temperatures are lower *per se*.

It may be that a reduction in weight of as much as 15 per cent. to 20 per cent. will ultimately be obtained by supercharging.

The question of cycles, two-stroke instead of four, is probably a change by which still greater reductions may be achieved; the use of the solid injection of fuel into the cylinder having very much increased the prospects of the two-stroke. More experimental work is wanted in both methods as the thermal limit (heat dissipation) so often intervenes.

Mechanically.—The reduction in weight by mechanical means must in the main be obtained by increased piston speed.

Increase of piston speed to obtain weight reduction has different effects in different types of engines or sets up different limitations. The limits are thermal and mechanical. For all types increased piston speed means more power per cylinder and therefore more heat flow, and increased cooling facilities must be provided. This is probably felt more in the air-cooled than in the water-cooled type; however, up to the present, heat dissipation has not proved to be a limiting factor. An experimental cylinder of 8in. bore by 10in. stroke has been constructed at the R.A.E. It has an aluminium head cast on to a steel barrel; the section of the head is spherical and four valves are fitted—two inlet and two exhaust.

There are certain limiting features in the speeds of engines, notably the loading at the big end of the connecting rod, and Table VI. is interesting, therefore, and reveals the state of affairs very clearly. It will be seen that the simple six can be run very much faster than the single plane radial—a point hardly sufficiently realised when comparing types. Further, if other considerations did not in turn become limiting factors, it is indicated that there is less difference between the weights of various types than is usually supposed. In examining this important limitation four engines were assumed, each having a capacity of 1,200 cubic inches, stroke bore ratio of 11 to 1, and a piston speed of 2,000 feet per minute.

The figures in Table VI. indicate that though the radial type may be the lighter in design, it is not necessarily so in practice, due to the crank pin load.

The rotary radial is limited by the centrifugal load of the cylinders and reciprocating parts and loss of power in rotation.

On the other hand, the plain six-cylinder line ahead, one of the most reliable of engines, can, other things being equal, increase its piston speed and so reduce its weight to 1.2 lbs. per B.H.P.; but this type may have difficulty with the valve gear when running at the higher rate of revolution to give the piston speed, and the necessary gearing required to give a reasonable propeller speed is no small problem.

Gearing is almost essential with all high-speed engines, and if added to the engines in the table now without it a material difference is made.

The Differential type combines the rotary and radial and reduction gearing, thus largely obviating the crank pin loading difficulty.

Valve gear operation and port area imposes a limit in all types. The crank pin load has different degrees of limiting effect on different types as has been shown, and the effect of counteracting forces such as the employment of centrifugal force to overcome this has been considered; similarly, centrifugal force was in the differential engine used with an all-tension valve gear. This allowed of a considerable reduction in weight, and hence a higher speed of gear. The sleeve valve as used in the Argyll engine illustrated by the next slide must also be considered.

The maintenance of volumetric efficiency is a difficult problem when the cylinder head already seems to be full of valves, and other types of construction may need to be adopted such as the principle used in the Monosoupape Gnome.

All valves may be used alternately for admission and exhaust with mechanical injection of fuel into the cylinder; to allow of the coupling up of pipework a director valve exterior to the valves on the combustion head must be used.

The indications are for dual purpose valves with direct injection of fuel for very high speeds.

Metallurgical.—We have now to consider the question of reducing of weight metallurgically. A table of specific gravities is shown* at Slide No. 34, and reveals considerably more possibilities than those so far considered; for instance, when we think of an engine like the 150 H.P. Gnome, shown at Slide No. 35, built entirely of steel having a specific gravity of 7.2, whereas that of the alloy electron is only 1.8, the prospects seem distinctly great.

The future of the light-weight alloys is not yet very clear with regard to the mechanical stresses they will ultimately be capable of carrying. If we suppose that in the course of time they can be produced so as to have a tensile strength of 40 tons per square inch and stand up to all other tests, fatigue included, that are obtained in the case of steel, then, of course, an extremely light engine seems possible below $\frac{1}{2}$ lb. per brake horse-power.

In connection with this part of the subject, the work of the National Physical Laboratory has been most signal.

The Lecturer is very strongly of the opinion that more development work in the production of light-weight alloys should be taken by private firms. Up to now it has largely been done by the N.P.L. and public funds, though credit must be given to the Institute of Mechanical Engineers for their Light Weight Alloys Committee.

At the present time only certain parts of an engine can be made from light-weight alloys. In the vertical type this has been almost fully carried out. In the radial, for instance, on the Gnome, it would almost appear that a further 25 per cent. reduction on the 1 lb. could be made mainly on the crank case. From what has been said it seems quite possible to produce an engine under 1 lb. per brake horse-power.

* At end of paper.—ED.

TABLE I.
AERO ENGINES BEFORE 1910.

Name of Engine	Wright.	Antoinette.	Anzani.	Green.	Wolseley.	Pipe.	Aster.	Renault.	Panhard.	Gnome.
Type of Engine	Vertical.	Vee.	Fan.	Vertical.	Vee.	Vee.	Vertical.	Vertical.	Vertical.	Rotary.
Cooling System	Water.	Water.	Air.	Water.	Water.	Water.	Water.	Water.	Water.	Air.
Number of Cylinders	4	8	3	4	8	8	4	4	4	7
Bore of Cylinders, inches	4.25	4.35	3.94	5.52	3.74	3.94	5.12	4.33	7.28	4.35
Stroke of Piston, inches	4.33	4.15	5.92	5.75	5.0	3.94	5.52	6.30	7.88	4.73
Brake Horse-Power...	24	49	25	60	54	55	51	38.5	112	45
Brake M.E.P., lbs./ sq. in.	64.48	60.52	65.33	78.50	88.47	58.15	88.86	74.71	75.15	65.85
Revs. per Minute	1200	1100	1400	1100	1350	1950	1000	1100	900	1100
Piston Speed, ft. per min.	870	760	1380	1015	1125	1280	925	1155	1180	870
Dry Weight of En- gine, lbs.	210	265	140	236	300	289	242	286	836	172
Weight per B.H.P. in lbs.	8.7	5.4	5.6	3.94	5.6	5.3	4.75	7.4	7.5	3.8

TABLE
PARTICULARS OF LEADING
GERMAN AEROPLANE

MAKE OF ENGINE.	BENZ.	MERCEDES-DAIMLER.						
		Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.
Type								
Number of Cylinders No.	4	6	4	4	4	6	4	4
Bore of Cylinders ... inches	5.12	4.13	4.72	5.51	4.72	4.72	4.33	4.72
Stroke of Pistons ... inches	7.09	5.51	5.51	5.90	5.51	5.51	5.51	5.51
Brake Horse-Power... B.H.P.	101.2	88.9	71.3	99.1	70.4	103.0	60.8	66.3
Brake Mean Pressure lbs./□"	107.0	114.2	103.5	102.0	107.5	107.0	104.8	98.0
Revs. per Minute ... R.P.M.	1288	1387	1412	1373	1343	1315	1369	1391
Piston Speed... .. ft./min.	1523	1274	1297	1350	1233	1207	1282	1278
Fuel per B.H.P. Hour lb.	0.47	0.51	0.50	0.49	0.50	0.53	0.50	0.50
Weight of Engine complete with Cooling System ... lbs.	425	390	352	490	379	541	337	382
Weight per B.H.P.... lbs.	4.20	4.37	4.91	4.91	5.36	5.23	5.51	5.72
Weight of Power Plant with Fuel, Oil and Tanks for 4 Hours lbs.	657	605	525	719	545	799	502	546
Weight of Power Plant per B.H.P.... lbs.	6.48	6.81	7.37	7.25	7.74	8.21	8.26	8.22

TABLE
PARTICULARS OF LEADING
BRITISH WAR

MAKE OF ENGINE.		ARGYLL.	BRITISH ANZANI.	BEARDMORE AUSTRO-DAIMLER.	
				Vertical.	Vertical.
Type		Vertical.	Radial.		
Number of Cylinders	No.	6	10	6	6
Bore of Cylinders ...	inches	4.92	4.53	4.72	5.12
Stroke of Pistons ...	inches	6.89	6.10	5.51	6.89
Brake Horse-Power...	B.H.P.	116.6	100.2	95.5	129.0
Brake Mean Pressure	lbs./□"	97.2	72.5	102.0	94.3
Revs. per Minute ...	R.P.M.	1200	1110	1279	1275
Piston Speed ...	ft./min.	1378	1129	1175	1464
Fuel per B.H.P. Hour	lb.	0.57	0.95	0.69	0.54
Weight of Engine complete with Cooling System ...	lbs.	600.0	464.0	437.1	583.8
Weight per B.H.P....	lbs.	5.15	4.64	4.68	4.52
Weight of Power Plant with Fuel, Oil and Tanks for 4 Hours	lbs.	919.2	958.7	738.1	904.6
Weight of Power Plant, etc., per B.H.P.	lbs.	7.9	9.5	7.7	6.96

2.
ENGINES IN 1914. TEST FIGURES.
ENGINE TRIALS, 1913.

ARGUS.			N.A.G.		MULAG.	SCHROTER.	BAYER- ISCHEN.	GYRO.
Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Vertical.	Rotary.	Rotary.
4	4	6	4	4	6	6	7	7
5.51	4.92	4.92	5.31	4.72	4.33	4.88	4.33	4.29
5.51	5.12	5.12	6.30	4.72	6.69	6.30	4.72	4.76
96.6	71.0	102.0	95.6	95.8	101.7	88.7	37.4	38.7
106.4	107.5	101.1	101.0	95.0	101.1	79.2	66.6	77.0
1368	1342	1370	1344	1408	1346	1252	1031	954
1256	1145	1169	1109	1400	1557	1314	812	757
0.53	0.59	0.59	0.52	0.49	0.53	0.63	0.86	0.77
427	357	536	279	476	588	468	177	186
4.40	5.00	5.22	4.96	4.98	5.76	5.27	4.72	4.80
692	566	829	409	696	834	705	340	351
7.16	7.98	8.12	7.33	7.28	8.21	7.94	9.10	9.07

3.
ENGINES IN 1914. TEST FIGURES.
OFFICE TRIALS, 1914.

DUDBRIDGE ALMSON CANTON-UNNE.			BRITISH GNOME MONOSOUPE.		GREEN.		SUNBEAM.	WOLSELEY. F2. RENAULT.	
Radial.	Radial.	Radial.	Rotary.	Rotary.	Vertical.	Vertical.	Vee.	Vee.	Vee.
7	9	14	9	9	6	6	8	8	12
4.72	4.72	4.72	4.13	4.13	5.51	5.51	3.54	5.00	3.78
5.51	5.51	5.51	5.90	5.90	5.98	5.98	5.90	7.00	5.51
89.0	124.0	185.0	99.2	104.2	101.7	103.5	130.9	139.6	113.5
82.3	89.0	83.5	92.0	96.0	75.5	77.0	108.7	81.0	67.3
1275	1276	1307	1206	1205	1246	1242	2046	1238	1800
1171	1172	1200	1187	1186	1243	1239	2014	1445	1654
0.58	0.55	0.61	0.69	0.72	0.67	0.63	0.53	0.58	0.66
32.9	545.6	780.2	275.0	275.0	506.1	507.3	565.1	810.7	478.8
4.86	4.40	4.22	2.77	2.64	4.97	4.90	4.32	5.81	4.22
71.9	871.5	1303.9	655.4	716.0	835.2	818.2	896.1	1190.6	863.2
7.55	7.20	6.95	6.60	6.86	8.22	7.91	6.84	8.54	7.60

TABLE 4.
COMPARATIVE TABLE OF TYPES.

TYPE OF ENGINE.	NAME OF ENGINE.	PERFORMANCE AT NORMAL PISTON SPEED AND NORMAL BRAKE MEAN PRESSURE.				PERFORMANCE WITH NORMAL PISTON SPEED AND 130LBS. PER SQ. IN. B.M.E.P.				PERFORMANCE WITH NORMAL AND SPEED 2,000FT./MIN. PISTON SPEED OF 2,000FT./MIN.			
		Weight per B.H.P. in lbs.	Piston Speed Feet/Min.	B.M.E.P. lbs. per sq. in.	Weight per B.H.P. in lbs.	R.P.M.	Weight Lbs./ B.H.P.	R.P.M.	Weight Lbs./ B.H.P.	R.P.M.	Weight Lbs./ B.H.P.	R.P.M.	Weight Lbs./ B.H.P.
Vertical Water Cooled ...	" Puma "	...	1400	118.1	240	2.96	1400	264	2.84	1605	275	2.50	1605
Vee Water Cooled ...	300 h.p. Hispano Suiza	2.65	1800	116.8	300	2.38	1800	334	2.34	2160	339	1.99	2160
Vee Water Cooled ...	Rolls-Royce Eagle	...	1800	124.0	350	3.21	1800	367	3.28	1847	359	3.13	1847
Vee Water Cooled ...	Liberty ...	...	1650	118.0	405	2.44	1650	446	2.59	1715	420	2.34	1715
Arrow Water Cooled	Napier " Lion "	...	2000	122.0	450	2.40	2000	480	2.19	2340	526	2.06	2340
Rotary Air Cooled ...	B.R.2 ...	...	1300	95.2	238	1.53	1300	325	1.60	1690	310	1.17	1690
Radial Air Cooled ...	Cosmos " Jupiter "	...	1650	109.5	400	1.47	1650	475	1.80	1600	388	1.52	1600

TABLE 5.
LONDON-PARIS SERVICE.

Type of Engine	...	...	...	...	...	...	a	b	c
Brake Horse Power of Engine	...	...	...	...	...	B.H.P.	500	500	500
Weight per B.H.P.	...	...	...	...	...	lbs.	1.5	2.5	3.5
Fuel and Oil Consumption per B.H.P. Hour	...	...	...	...	...	lbs.	0.6	0.5	0.45
Weight of Power Unit, Fuel, and Oil, for 2½ Hours	...	...	...	...	...	lbs.	1500	1875	2312
Weight of 5 Passengers at 160 lbs. Each	...	...	...	...	...	lbs.	800	800	800
Weight of Power Unit, 5 Passengers, Fuel and Oil for 2½ Hours	...	...	...	...	...	lbs.	2300	2675	3112
Saving of Weight Based on Engine "C"	...	...	...	...	...	lbs.	812	437	nil.
Number of Passengers Equivalent to Saving of Weight	...	...	...	...	...	—	5	3	nil.
Total Number of Passengers that could be Carried	...	...	...	...	...	—	10	8	5
Total Earnings at £10 10s. od. per Passenger for 50 Flights	...	...	...	...	...	—	£5250	£4200	£2625
Running Time Allowed between Overhauls	...	...	...	...	...	Hours.	50	100	150
Total Running Time for 50 Flights	...	...	...	...	...	Hours.	125	125	125
Number of Overhauls	...	...	...	...	...	—	2.5	1.25	0.83
Cost of Upkeep and Replacements assuming £50 per Overhaul	...	...	...	...	...	—	£125 0 0	£62 10 0	£41 13 0
Cost of Fuel at 4/- per Gallon for 50 Flights	...	...	...	...	...	—	£1000 0 0	£833 6 8	£750 0 0
Total Cost for 50 Flights	...	...	...	...	...	—	£1125 0 0	£895 16 8	£791 13 0
Nett Earnings for 50 Flights	...	...	...	...	...	—	£4125 0 0	£3304 3 4	£1833 7 0

TABLE 6.

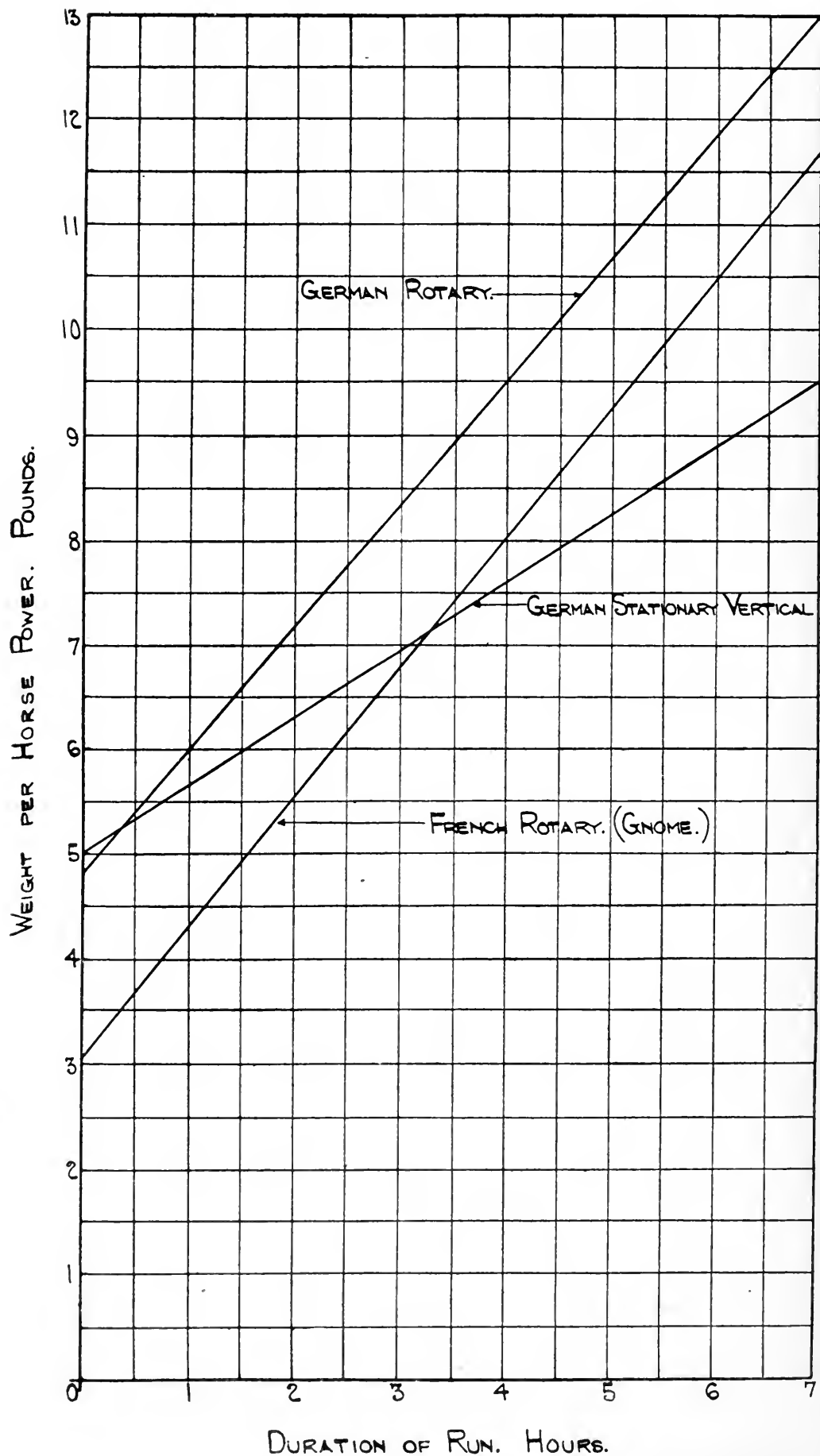
Engine	...	...	...	...	...	...	...	...	...	<i>a</i> Vertical.	<i>b</i> Vec.	<i>c</i> Arrow.	<i>d</i> Radial.
Type of Engine	...	...	...	...	...	...	...	...	...	6	12	12	9
Number of Cylinders	...	...	...	...	...	...	...	...	No.				
Bore of Cylinders	...	...	...	...	...	...	...	...	inches	6.00	4.78	4.78	5.25
Stroke of Pistons	...	...	...	...	...	...	...	...	inches	7.00	5.60	5.60	6.14
R.P.M. at Piston Speed of 2,000 Feet per Minute	...	...	...	...	...	...	...	...	R.P.M.	1715	2140	2140	1960
Rotary Weights	...	...	...	...	...	...	...	...	lbs.	5.10	5.82	7.45	16.4
Centrifugal Pressures	...	...	...	...	...	...	...	...	lbs.	1490	2120	2720	5480
Diameter of Crank Pin	...	...	...	...	...	...	...	...	inches	2.52	2.15	2.20	2.62
Effective Length of Bearing	...	...	...	...	...	...	...	...	inches	2.90	2.30	2.50	3.10
Projected Area	...	...	...	...	...	...	...	...	sq. ins.	7.50	4.95	5.50	8.12
Centrifugal Loading on Big End Bearing	...	...	...	...	...	...	...	...	lbs./sq. ins.	200	433	495	675
Rubbing Velocity	...	...	...	...	...	...	...	...	ft./sec.	18.85	20.10	20.50	22.40
Load Factor	...	...	...	...	...	...	...	...	lbs. ft./sec.	3770	8700	10150	15100
Permissible Increase in R.P.M. for Constant Centrifugal Loading (<i>d</i>)	...	...	...	...	...	...	...	...	Per Cent.	84	25	17	0
Permissible Increase in R.P.M. for Constant Load Factor (<i>d</i>)	...	...	...	...	...	...	...	...	Per Cent.	59	20	14	0

TABLE 7.

SPECIFIC GRAVITIES OF VARIOUS METALS.

Lead	...	...	...	...	...	...	11.0
Copper	...	...	...	...	...	...	8.9
Nickel	...	...	...	...	...	...	8.7
Bronze	...	...	...	...	...	...	8.7
Steel	...	...	...	...	...	...	7.8
Wrought Iron	...	...	...	...	...	...	7.7
Cast Iron	...	...	...	...	...	...	7.5
Manganese	...	...	...	...	...	...	7.4
Tin	...	...	...	...	...	...	7.0
Zinc	...	...	...	...	...	...	7.0
Chromium	...	...	...	...	...	...	6.8
Antimony	...	...	...	...	...	...	6.6
Aluminium (Commercial)	...	...	...	...	...	...	2.6
Magnesium	1.75

CURVES SHEWING INITIAL WEIGHT PER HORSE POWER
AND DURATION OF RUN.



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MAY, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Council.

As a result of the ballot of members declared at the Annual General Meeting the full Council for the year 1922-23 is as follows:—

Lieut.-Colonel M. O'Gorman, C.B. (Chairman); Brig.-Gen. R. K. Bagnall Wild, C.M.G., C.B.E.; Prof. L. Bairstow, C.B.E., F.R.S.; Mr. Griffith Brewer, Wing Commander T. R. Cave-Browne-Cave, C.B.E.; Sir Mackenzie Chalmers, K.C.B., C.S.I.; Mr. H. P. Folland, Sir Robert Hadfield, Bart., F.R.S.; Capt. G. de Havilland, A.F.C.; Squadron Leader R. M. Hill, M.C., A.F.C.; Prof. C. F. Jenkin, C.B.E.; Prof. B. Melvill Jones, A.F.C.; Lieut.-Col. J. T. C. Moore-Brabazon, M.C., M.P.; Mr. J. D. North, Lieut.-Col. A. Ogilvie, C.B.E.; Dr. A. J. Sutton Pippard, Major-Gen. Sir R. M. Ruck, K.B.E., C.B., C.M.G.; Col. the Master of Sempill, A.F.C.; Major R. V. Southwell, Lieut.-Col. H. T. Tizard, A.F.C.; Major H. E. Wimperis, O.B.E.; *Hon. Treasurer*, Mr. A. E. Turner.

Lectures.

The following programme of lectures has been arranged for next session:—

- Oct. 5. Prof. L. Bairstow, Fellow. "The Work of S. P. Langley."
,, 19. Mr. J. D. North, Fellow. "The Metal Construction of Aeroplanes."
Nov. 2. Major A. R. Low, Fellow. "A Review of Airscrew and Helicopter Theory, with Aeroplane Analogies."
,, 16. Mr. R. McKinnon Wood, Fellow. "The Co-relation of Model and Full-Scale Work."
Dec. 7. Prof. C. F. Jenkin. "Fatigue in Metals."
Jan. 4. (To be announced later.)
,, 11. Juvenile Lecture. (Title to be announced later.)
,, 18. (To be announced later.)
Feb. 1. Mr. G. S. Baker. "Ten Years' Testing of Model Seaplanes."
,, 15. Wing Commander Cave-Browne-Cave. "The Practical Aspects of the Seaplane."
Mar. 1. Major F. M. Green. "Helicopters."
,, 15. (To be announced later.)

Programme for the Students' Section.

Friday, April 28th.—Library of Royal Aeronautical Society, 6.45 p.m. Student's paper (postponed from March 23rd), "Some Notes on Commercial Aircraft," by Stanley H. Evans. Mr. H. P. Folland, Fellow, in the chair.

Saturday, May 6th.—Visit to the de Havilland Aircraft Works, Edgware. Meet at Works 10.0 a.m. Bus leaves Kilburn Park Station (Bakerloo Tube) at 9.30 a.m.

Wednesday, May 31st.—Visit to the Royal Aircraft Establishment, South Farnborough. Meet at 8.40 a.m. for special tickets at Booking Office, Waterloo Station (L. & S.W.R.) for 9.0 a.m. train.

Saturday, June 3rd.—Visit to the National Physical Laboratory, Teddington. Meet at 9.15 a.m. for special tickets at the Booking Office, Waterloo Station (L. & S.W.R.).

Students are requested to give in their names *immediately* for the visits they wish to attend in order to obtain cheap travel facilities. The Hon. Secretary will meet students at places and times mentioned for issue of these tickets.

Students are also asked to send in early this month (May) promises of papers for the Students' Section for next Session, 1922-1923.

Associate Fellowship Examination.

The Council have decided, as a result of representation which has been made to them, to hold the examination for Associate Fellowship in September instead of in April this year, as it has been found that this would be more convenient for the majority of students who desire to sit for the examination, owing to their studies having been delayed by the war. Intending applicants should forward their names to the Secretary not later than July 31st.

Library.

The Society's lantern is being repaired so as to make it available for students' discussion meetings and other meetings in the library. The Finance Committee have also authorised expenditure on extra bookcases, which are urgently needed. Will any member, therefore, who hears of a good bookcase, preferably oak, with glazed doors, kindly communicate with the Secretary?

The following books have been received and placed in the library:—"Grundlagen der Flügtechnik," Dr.-Ing. H. G. Bader. "Notes and Examples on the Theory of Heat and Heat Engines," John Case. "La Photographie Aerienne," A. H. Carlier. "Cours Pratique d'Aviation," Capt. Gambier and Lieut. de V. Amet. "Research in Industry," A. P. M. Fleming and J. G. Pearce. "Airplane Engines," L. S. Marks. "Gas, Petrol and Oil Engines," D. Clerk. "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Lüftfahrt," Dr.-Ing. L. Prandtl. "Ergebnisse der Aerodynamischen Versuchsanstalt zu Gottingen," Dr.-Ing. L. Prandtl. "Verhandlungen der Versammlung von Vertretern der Flugwissenschaft," Dr.-Ing. L. Prandtl. "Catalogue of the Collections in the Science Museum, South Kensington (Aeronautics)," Board of Education.

W. LOCKWOOD MARSH, *Secretary*.



ANNUAL GENERAL MEETING.

The Fifty-Seventh Annual General Meeting of the Society was held in the Society's Offices, 7, Albemarle Street, London, at 5.0 p.m., on Tuesday, March 28th, 1922. The Chairman, Lieutenant-Colonel M. O'Gorman, C.B., D.Sc., presided, and the following were present:—

Council.—Sir Mackenzie Chalmers, Lieutenant-Colonel A. Ogilvie, Dr. A. J. Sutton Pippard, Major R. V. Southwell, Major H. E. Wimperis.

Members.—P. Y. Alexander, R. L. Balston, Griffith Brewer, Miss L. Chitty, H. Glaser, Dr. Hilda Hudson, W. O. Manning, C. F. Dendy Marshall, H. A. Mettam, P. C. Thornton, Dr. R. Mullineux Walmsley, and F. P. Walsh.

Miss L. Chitty, Mr. R. L. Balston and Mr. W. O. Manning were appointed scrutineers of the ballot for the election of Council.

The Chairman, in presenting the Council's report and balance sheet, said that though there had been a slight drop in the membership, he did not think this was surprising in view of the bad times being experienced in aviation. He felt that members could do a great deal to induce more members to join the Society. Besides the technical grades of the Society, there were the subscribing grades, to which anyone interested in the subject and sufficiently well-wishing to the cause was eligible. The fact that the membership had not dropped more was due to the activity of their energetic staff.

He called attention to the benefits which the Society now offers in the way of prizes. There is the Silver Medal of the Society, which is awarded to the best Paper published in the JOURNAL in the year; and for Students there is the Society's Bronze Medal, for the best Paper by a Student published in the JOURNAL during the year. Besides these there is the Pilcher Memorial Prize for Students, to be awarded to the best Paper in each year inaugurating discussion at one of the Students' Meetings. The Students' Section had had several meetings for discussion, and an interesting programme of visits had been arranged for the summer.

Another point which he would like to mention was the technical lectures before the Society. He thought that many members miss a great deal by not attending these meetings, and he felt sure that they would come if they realised how very good they are. Reading the papers in the JOURNAL afterwards was quite a different thing from actually hearing them read and discussed.

In conclusion he read the Honorary Treasurer's statement on the financial position, which showed that members could congratulate themselves on a considerable improvement.

The adoption of the Report was proposed by Colonel Ogilvie, seconded by Mr. Dendy Marshall, and carried unanimously.

The scrutineers then presented the result of the ballot, and the following members were declared elected to serve on the Council for the two years ending March, 1924:—

Brigadier-General R. K. Bagnall Wild, C.M.G., C.B.E., Mr. Griffith Brewer, Mr. H. P. Folland, Squadron Leader R. M. Hill, M.C., A.F.C., Professor C. F. Jenkin, C.B.E., Professor B. Melvill Jones, A.F.C., Mr. J. D. North, Lieutenant-Colonel A. Ogilvie, C.B.E., Dr. A. J. Sutton Pippard, and Major H. E. Wimperis, O.B.E.

The meeting closed with a vote of thanks to the scrutineers and the Chairman, proposed by Sir Mackenzie Chalmers.

PERFORMANCE TESTING OF AIRCRAFT.

*Lecture delivered before the Cambridge University Aeronautical Society on
February 8th, 1922, by Squadron Leader T. M. Barlow.*

Introduction.

One of the factors contributing to the rapid development of aviation during the last few years has been the testing of aircraft conducted on systematic and scientific lines. Even more so, perhaps, future development is dependent on this branch of aeronautics especially when one considers we are still in the early stages of experimental research. Theories are excellent in their own sphere, but when applied to aviation must be treated with more respect than usual, as failure to materialise in practice is a matter of personal risk apart from the financial aspect of the case. Designers and constructors cannot make real progress unless they are provided with accurate and reliable data from performance trials of aircraft. Model testing, intricate mathematical calculations and assumptions do much towards predetermination of results, but after all the main thing that matters is practice, whether concerned with military or civil aircraft. In fact, the performance testing of aircraft forms that connecting link in the union of theory and practice which is absolutely essential for the efficient success (efficient in all senses of the word) of any machine or engineering structure.

I propose in this paper to give an outline of the performance testing of aeroplanes, as carried out in this country, with special reference to the routine work at the R.A.F. Aeroplane Experimental Establishment, Martlesham Heath. At this point I should like to place on record the fact that the general scheme of aircraft testing, as given in Col. Tizard's paper read before the Royal Aeronautical Society in 1917, has formed the base on which has been constructed and developed the present methods.

Standard Atmosphere.

Comparison of aircraft performances obtained from data of test flights carried out in different places and under various atmospheric conditions cannot be made unless such results are corrected to the performances which the aircraft would have if flown under identical atmospheric conditions. It is essential, therefore, that some form of standard atmosphere should be adopted. In England until quite recently, a mean of atmospheric records observed by the Meteorological Office during several years was taken as standard. This agreed remarkably well with the climate in East Suffolk (Martlesham Heath). France adopted Radaus law for variation of temperature and pressure with height. The United States, I believe, for a time worked to both. It was with a view to co-ordinating all available information on the subject that the Technical Section of the French Air Service, after considerable research into meteorological records of England and Europe, was able to arrive at simple empirical laws for a standard atmosphere. Present information states it is extremely probable that this standard will become international. At present it is used by both the English and French Technical Services.

The standard atmosphere is based on a straight line law for variation of temperature from given initial ground level conditions to a height of 11,000 metres. Above this height is considered isothermal.

The following are the main empirical equations and conditions of the standard atmosphere.

(1) Ground level. Zero height.

Height in metres. $H = 0$.

Temperature in degrees Centigrade. $\theta = 15^\circ$.

Pressure $= P_0 = 10.33$ kgs. per sq. metre.

Corresponding to 760 mm. of mercury.

This gives a standard density of 1.225 kgms. per cub. metre.

(2) From 0 — 11,000 metres.

Law of Temperatures.

$$\theta_H = 15 - 0.0065H.$$

Law of Pressures.

$$P_H/P_0 = \{ (288 - 0.0065H)/288 \}^{5.255}$$

Law of Densities.

$$\rho_H/\rho_0 = \{ (288 - 0.0065H)/288 \}^{4.255}$$

(3) Above 11,000 metres (Isothermal).

Law of Temperatures.

$$\theta_H = 56.5^\circ.$$

Law of Pressures.

$$\log P_H/P_0 = (H - 11000)/14600.$$

Law of Densities.

$$P_H/P_0 = \rho_H/\rho_0.$$

The agreement between this temperature gradient law and the average experienced in East Suffolk during twelve months is shown in Fig. 1. This has been prepared from the temperature records of all test flights carried out during the year up to 17,000ft. The chart also shows the limits of winter and summer observations.

The empirical laws give us a standard height and a variation of density, and charts showing this relationship, preferably expressed as percentage of standard density (ground level), form the means of reference from correcting the actual flight results to the standardised form for comparison purposes.

A further assumption, and a most important one, is that engine torque varies in proportion to the density of the surrounding air. This is not strictly correct. Tests carried out at the Royal Aircraft Establishment, Farnborough, U.S.A. and France on engines run in sealed chambers under artificial height conditions have shown that variation in proportion to pressure is a true assumption. However, actual flight trials under winter and summer variations of density do not give appreciable differences in performance when reduced to standard atmospheric conditions on the density assumption. Apart from this, the method is simpler and quicker; also there is no need for engine power curves to be taken during the trials. On consideration having been given to these points and bearing in mind that all results are comparative, both French and English testing aerodromes have adopted the assumption.

The reduction of results works out in a very straightforward and easy way. Before going on to describe the general proceedings to be adopted in testing I propose to outline the method.

To obtain the density of the surrounding air in which an aeroplane is flying one requires readings of pressure and temperature. The former are obtained by using either the ordinary form of altimeter with a fixed zero or recording barograph, the readings being pressures. The temperature of the air is read from special thermometers fixed in a suitable position. From these two readings the density can be calculated or preferably read off from suitable charts and is

best expressed as a percentage of the standard density. From the relationship between standard height and density it is thus possible to obtain the standard height of the aeroplane.

Both speed and climbing qualities of the aeroplane are referred to this standard height.

Dealing with climb first, by means of an altimeter and stopwatch or recording barograph aneroid rate of climb can be obtained at any height and therefore at any standard height by taking tangents to the aneroid height time curve. But

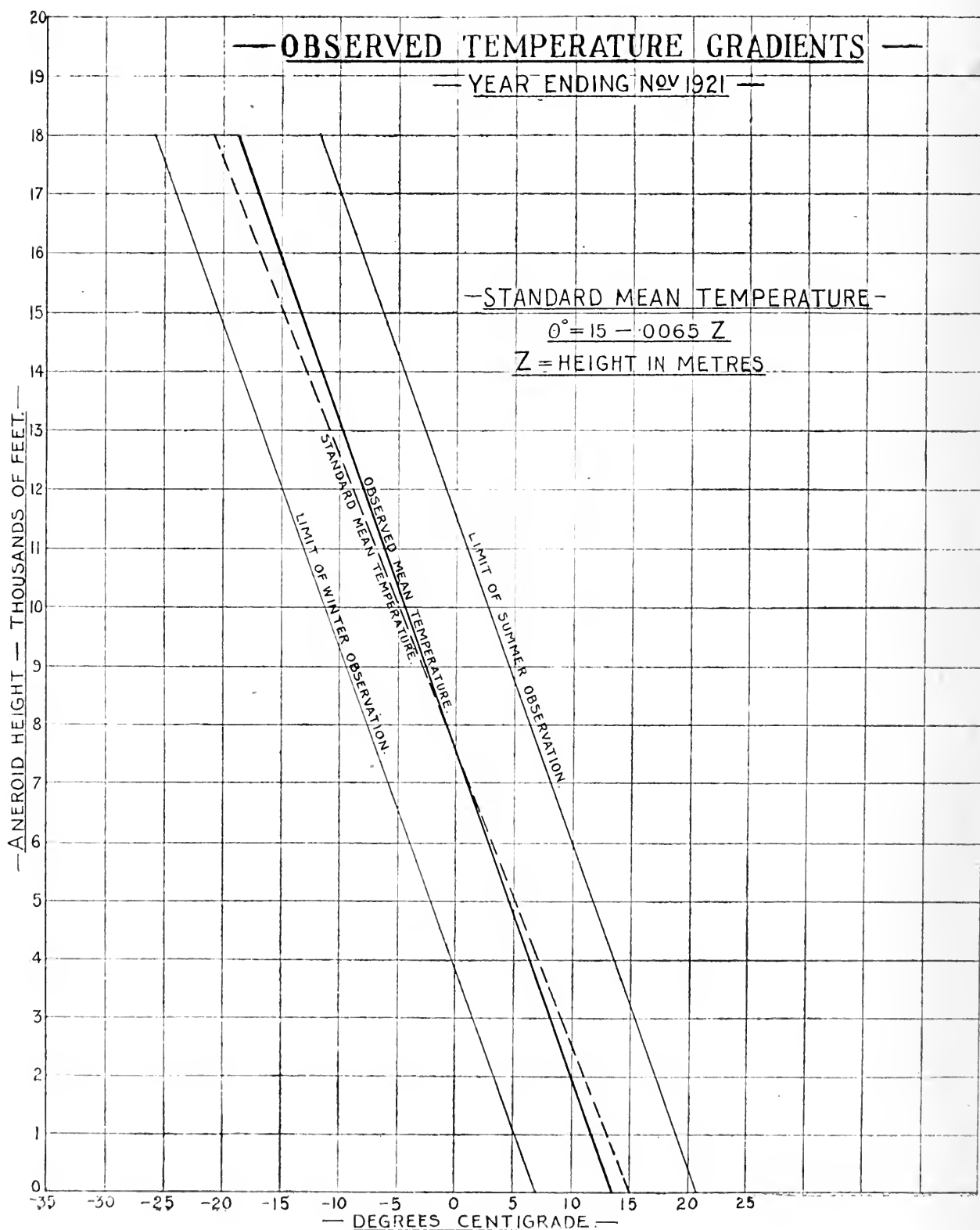
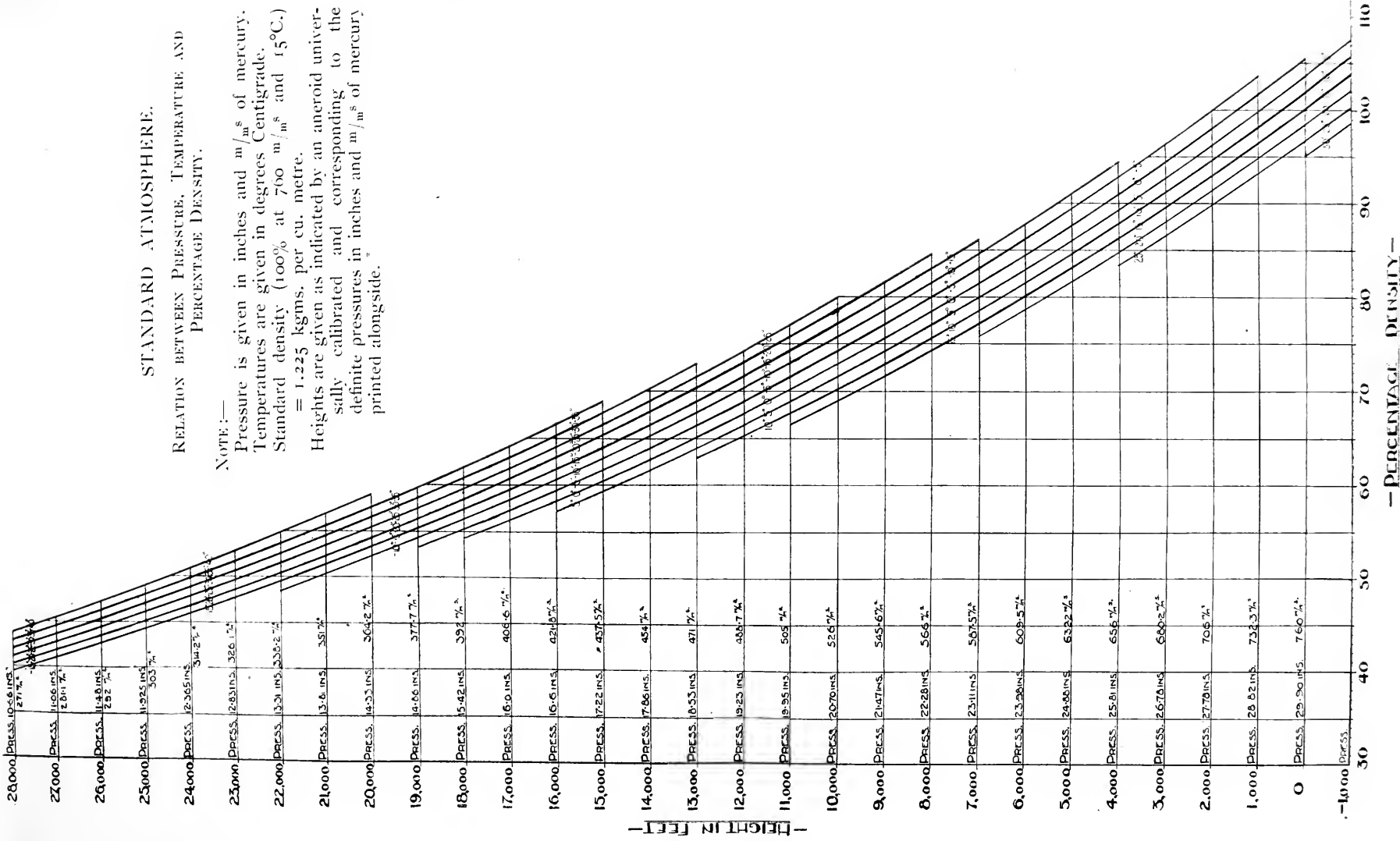


FIG. 1.



the aneroid or barograph can only record true change of height at its international calibration standard 10° Centigrade and must be corrected in the ratio of absolute temperatures before being plotted as a rate of time curve against standard height, *i.e.*, the factor is :—

$$C = (273 + t^{\circ})/283 \text{ where } t = \text{temperature in degrees Cent.}$$

Having thus obtained time rate of climb at any standard height by reversing the procedure an actual standard height time curve follows.

True speeds at any standard height are calculated from the air speed readings after due allowance has been made for pitot and instrument errors in the ordinary way by dividing by density.

The charts referred to are shown in Figs. 2, 3 and 4.

General Procedure for Performance Testing of an Aeroplane.

Although an aeroplane will be taken as an example, it should be understood that the methods used apply equally well to seaplanes, flying boats and amphibians with quite minor modifications. The order of operations is :—

- (1) General particulars of the aeroplane. Weighing and determination of centre of gravity.
- (2) Preliminary handling flight tests and climbing speed trials.
- (3) Speed course.
- (4) Climbing and speeds at height tests.
- (5) Special tests, consumption trials, "getting off" and "landing" trials.

(1) General Particulars of the Aeroplane.

In considering a performance report on any particular aeroplane one must be absolutely sure of the main features of the design. I mean that wing areas, control surfaces, all rigging angles, thrust line position, propeller pitch and diameter, etc., must be taken by actual measurement and observations. It is not sufficient to trust to drawings as often, especially in experimental work, quite important modifications are put through and by an oversight not recorded on the drawings. This preliminary ground work, therefore, although simple, must be done with extreme accuracy and cross checked where possible. Weighing, perhaps, is all important, and is the clue to the many differences in performances obtained by pilots at different aerodromes. It should be done by schedule, *i.e.*, from the weight bare a full detailed list is necessary of all additions to bring the aircraft up to its specified military or civil load. This sounds quite easy but is often confusing, as minor things like gun mountings, part of useless gear, small amounts of petrol in gravity tank overlooked make a difference in the final balance sheet. The weighings necessary are :—

- (a) Weight light, *i.e.*, no petrol or oil, but water in cooling system if not air-cooled engines, no live load and no military load as, for example, bomb racks, wireless, etc.
- (b) Weight full of fuel; also petrol and oil tanks filled up, quantity being measured. By taking the specific gravity a check on the first weight is obtained.
- (c) Weight with specified load. This, in the case of service aircraft, includes all crew, military load, and in the case of civil aircraft crew and passengers, luggage, etc.

The actual position of the centre of gravity should be taken during weighings light with specified load, thus again giving a check.

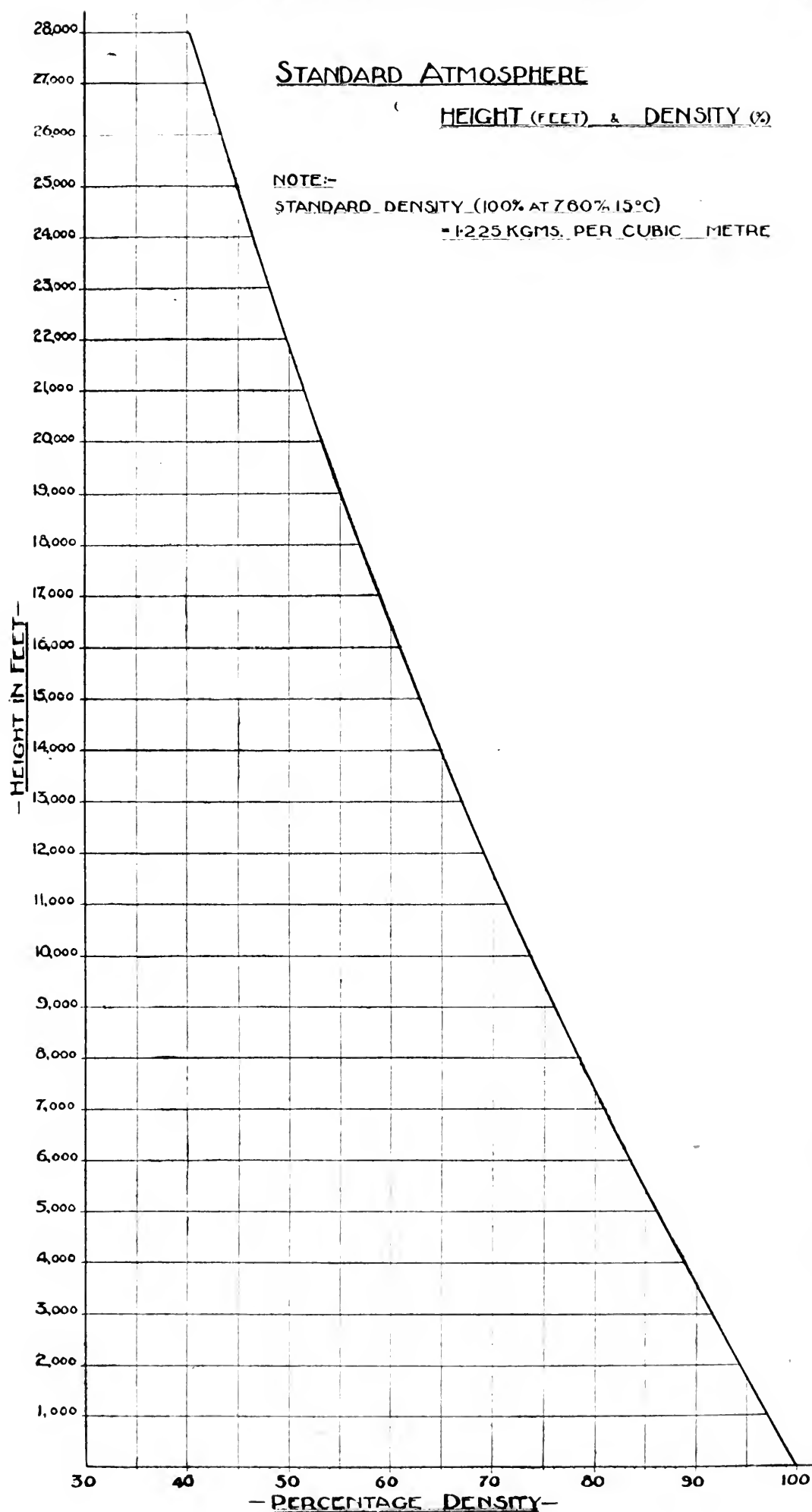


FIG. 3.

I should like to emphasise the importance to know the actual C.G., as with large aircraft it is extremely difficult to predetermine its position by calculation under full load conditions. If, therefore, the C.G. turns out to be somewhat extraordinary for the wing section used, immediate steps can be taken for readjustment of weights before full load flight tests are made. Even the best designers' C.G.'s do go astray sometimes simply because they are confirmed optimists.

The principle of determination is the usual one of taking the wheel and skid loads in two positions, *i.e.*, with tail down and raised. The actual measurements taken in practice vary, but Fig. 5 gives an accurate method of arriving at the position using the standard reference measurements which are the distance along the chord from the leading edge of the lower plane and the vertical distance above or below this chord. With ordinary trigonometrical equations the above are all that are required to give OX and OY and thus position the C.G.

In the case of an aeroplane with a variable chord wing section some definite chord must be fixed, *i.e.*, by quoting chord at a certain distance out from the centre.

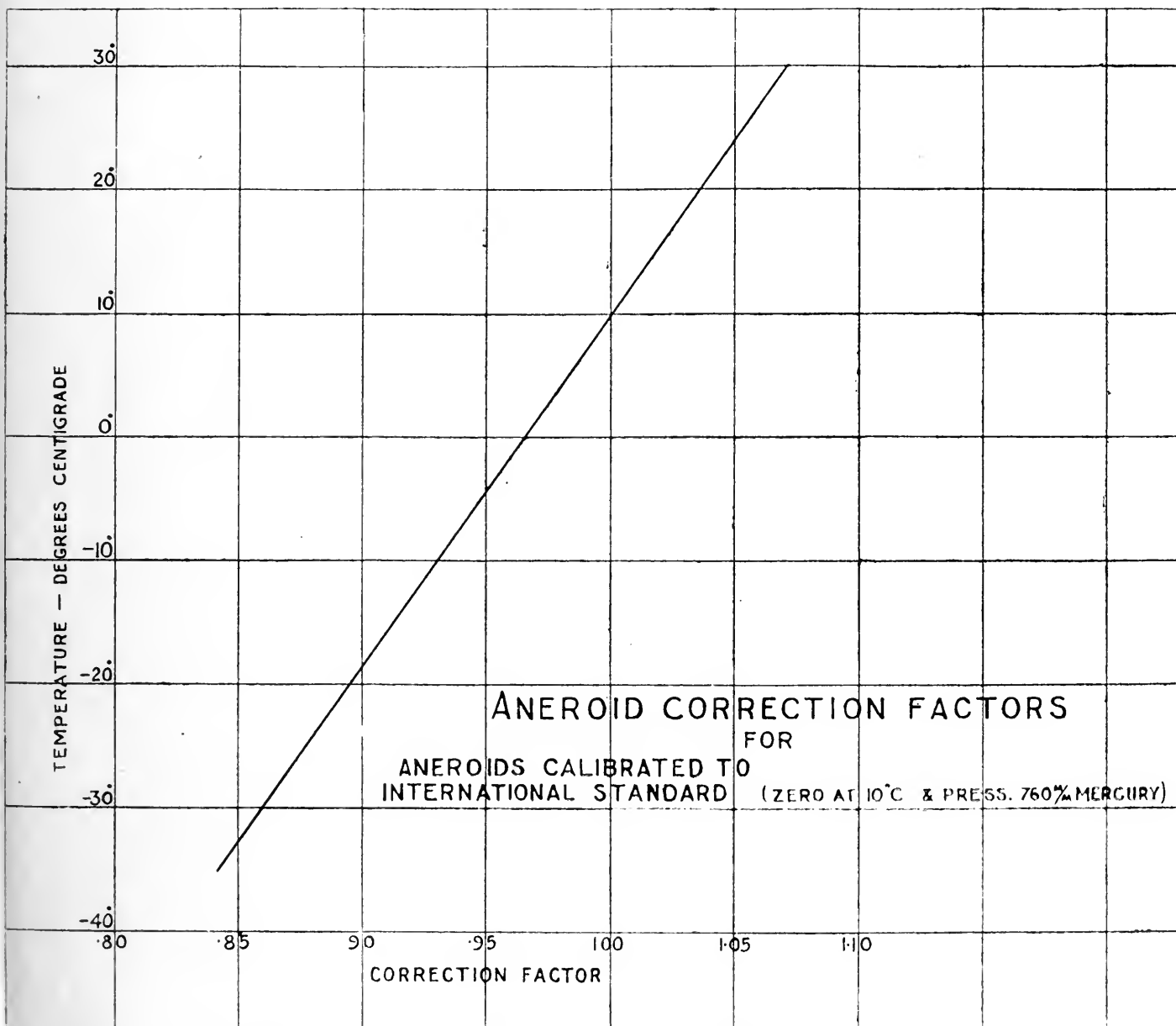


FIG. 4.

Apart from the ordinary weighing precautions there are two points to watch. First, the aeroplane must be out of all wind; secondly, the skid must be locked in one position so that there is not side load on the top of the tail skid weighing machine which might cause binding. If there is a big difference in tail load in the two positions it is possible for the shock-absorbing gear on the undercarriage to give a little and vary the distance of wheel centre relative to the chord. This may be prevented according to design of gear used.

(2) Preliminary Handling Tests and Climbing Speed Trials.

These flights are essential so that the test pilots can familiarise themselves with engine and aeroplane controls and any tricks for "landing" or "taking off." A test pilot must, during actual performance flights, be able to give his whole

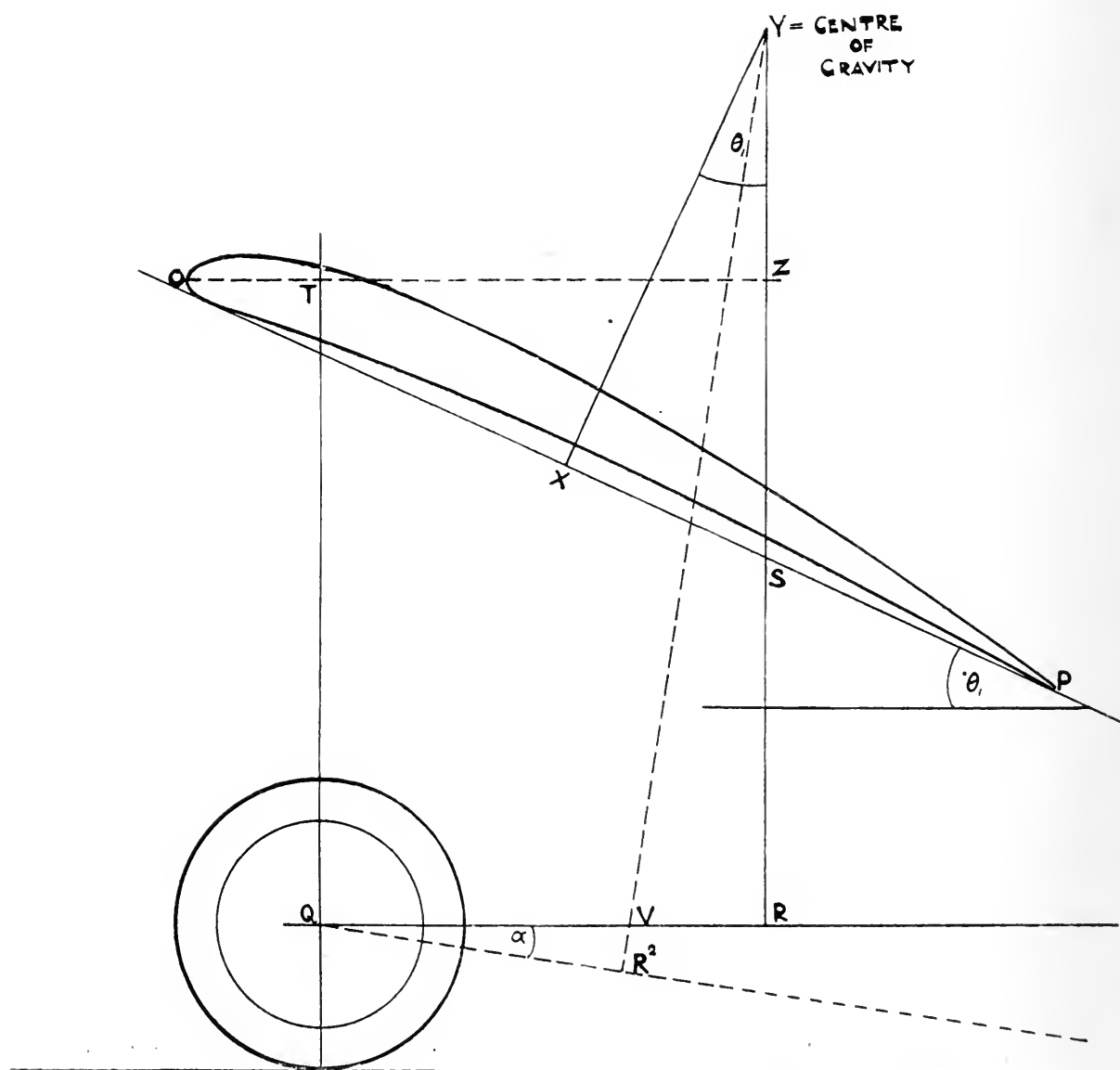


FIG. 5.

W = Total weight.

w_1 = Weight on tail in 1st position.

w_2 = " " " 2nd " " tail of aeroplane being turned through α .

L_1 and L_2 = Horizontal distances between tail skid and wheel centres for the two positions.

θ_1 and θ_2 = The angles of incidence for the two positions $\alpha = \theta_1 - \theta_2$.

H = Height of leading edge of reference chord above wheel centre = QT .

h = Horizontal distance of leading edge from the wheel centre = OT .

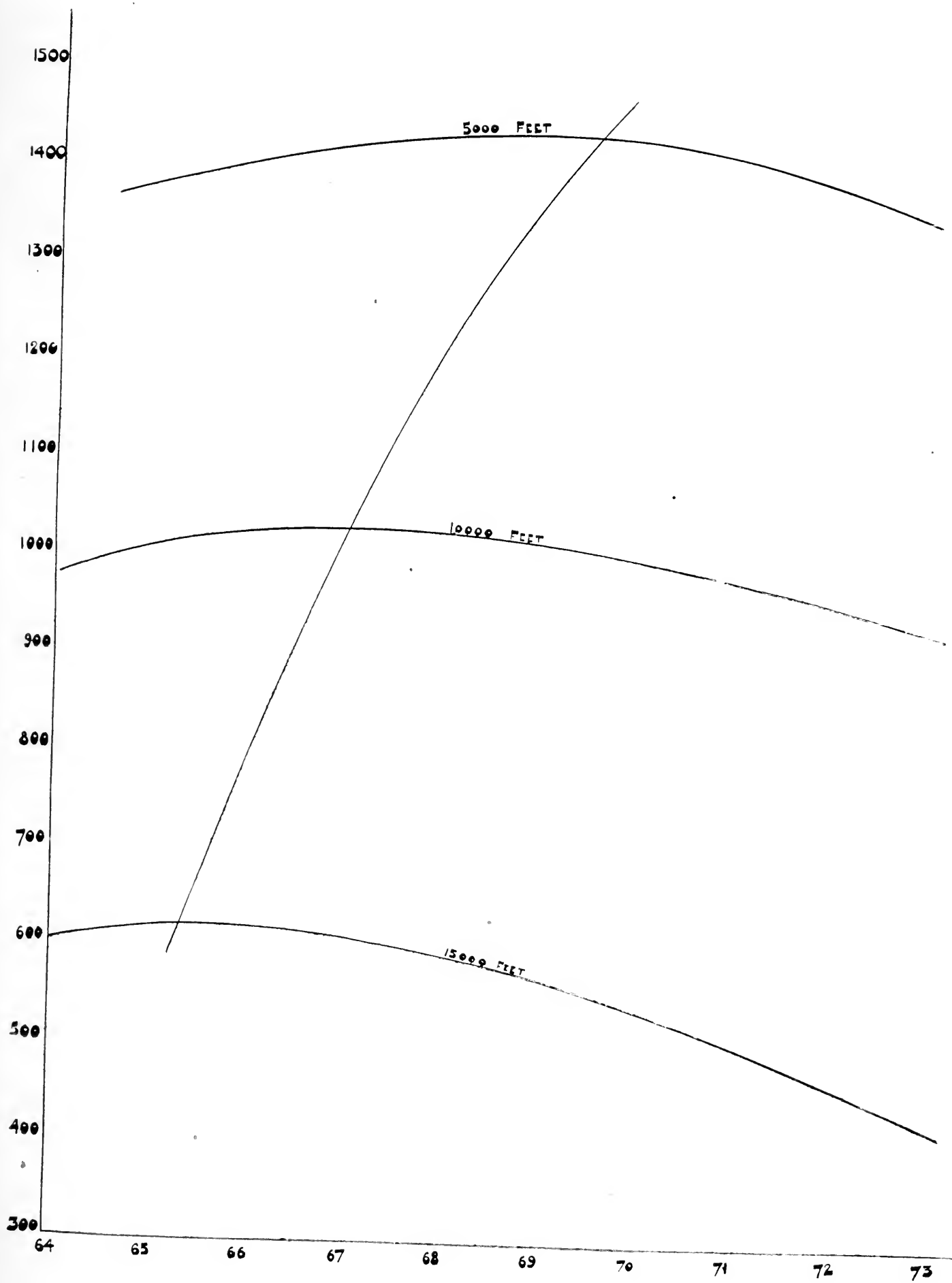


FIG. 6.—Tests for Climbing Speeds.

attention to the particular test being carried out, the actual flying and control being as natural as possible.

The best practice is to fly the aeroplane lightly loaded before full load is tried. During this period any minor modifications can be made which are often necessary. Full load climbing speed tests form the first real flight test. The aeroplane is climbed at different A.S.I. readings for 1,000ft. at various heights against stopwatch. A series of curves are then plotted from which the best range of climbing A.S.I. speeds follow (see Fig. 6).

(3) Speed Course.

The air-speed indicator of an aeroplane, apart from density correction and actual instrument errors, very rarely gives the true speed on account of pitot position errors. The pitot head is very sensitive to any position other than straight to wind and also to any slightly disturbed air flow in the neighbourhood. To correct for all possible errors, actually timing the aircraft over definite distances has proved to be the most efficient method. In the case of scouts and small aircraft this is best done over a ground course. For heavier aircraft the camera obscura system undoubtedly gives the more correct results, as the pilot is able to concentrate more on the test than he would do when flying a large aeroplane at level speeds about 20ft. to 30ft. off the ground—a risky procedure.

For the ground speed course at Martlesham Heath a tape machine apparatus is used. This consists of an ordinary motor-driven tape machine fitted with two ink pens which as the tape passes through gives two parallel straight lines. To obtain a time scale, one pen is clicked at right angles to the line by means of a solenoid worked through a seconds pendulum and electric contacts. The second pen can be clicked in a similar way by tapping keys at each end of the measured course, which are electrically connected. Two operators through suitable sights can thus obtain a permanent record of the time over the course. Fig. 7 shows the electrical connections of the apparatus together with an actual tape record. The record is part of the speed test of the Napier "Lion" Mars I. of the Gloucester Aviation Co. when breaking the speed record.

To obtain sufficient points for a correction curve the aeroplane is flown at five different air speeds (highest to lowest) up and down the course. Strength of wind and direction of wind are specially noted for each run and allowed for. If V_1 is the average of the speeds up and down the course and the wind speed is W at an angle ϕ to the course, it follows that:—

$$V \text{ true speed} = \{ V_1^2 + (W \sin \phi)^2 \}^{\frac{1}{2}}$$

i.e., air speed is equal to the square root of the sum of the squares of the mean speed and the component of the wind across the course. The effect of an error in wind measurement varies.

(a) Any moderate error in the measurement of a wind across the course is negligible. Thus a wind of 3 to 5 m.p.h. across the course only affects the results by $\frac{1}{3}$ per cent. if the aeroplane is moving at 60 m.p.h. and by $\frac{1}{8}$ per cent. if it moves at 120 m.p.h.

Since trials are not done in a strong wind, the whole correction for wind across the course is always very small and an error of 30 per cent. in its measurement is permissible.

(b) With a steady wind up and down the course, errors of measurement are also negligible since their effects are completely eliminated by taking the mean of the speeds up and down the course.

(c) With a variable wind up and down the course, large errors may occur. Thus, if during a flight in one direction the wind speed is 1 m.p.h. more than during the return flight in the opposite direction, an error of $\frac{1}{2}$ m.p.h. is caused.

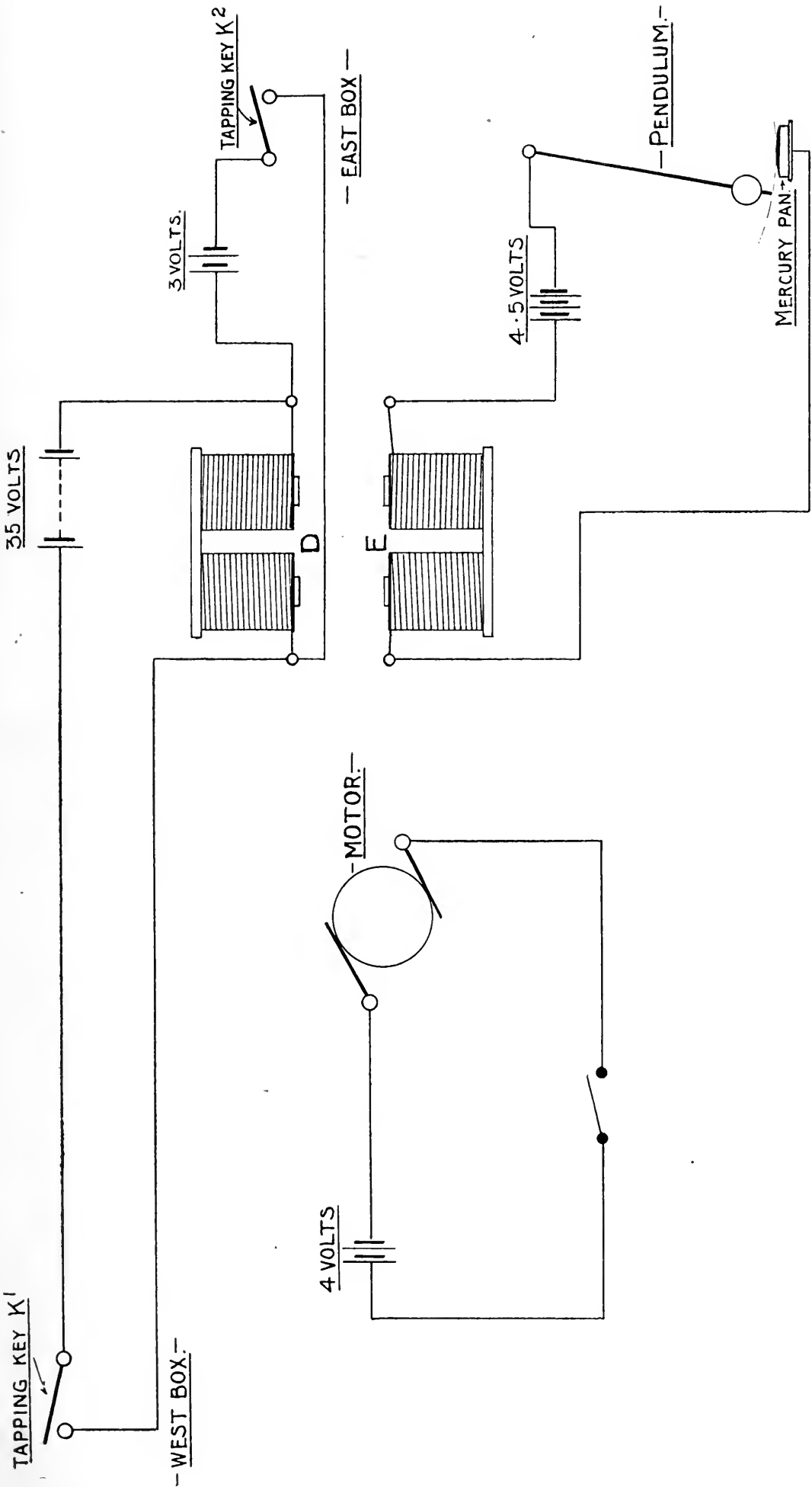


FIG. 7.—Wiring Diagram of Electrical Timing Apparatus.

This error may be caused either by variations in the wind itself or by the aeroplane flying at a slightly different height above the ground. Consequently it cannot be eliminated, and speed measurements in a wind which has an appreciable component of velocity up and down the course are not likely to be very accurate. Speed course trials at Martlesham Heath have been confined to occasions when there was no appreciable wind along the course.

Camera Obscura System for Speed Tests.

The principle of the apparatus is well known, but the actual calculations involved in the practical use may perhaps be worth while detailing.

The system consists of two lenses situated at the ends of a given base line (Fig. 8). One lens A has its optic axis vertical, and the optic axis of the second lens B lies in the vertical plane containing the optic axis of A, but is inclined towards A at some convenient angle to give a suitable field of observation. A convenient angle is 45° . The lenses should be of the order of 20 to 24 inches

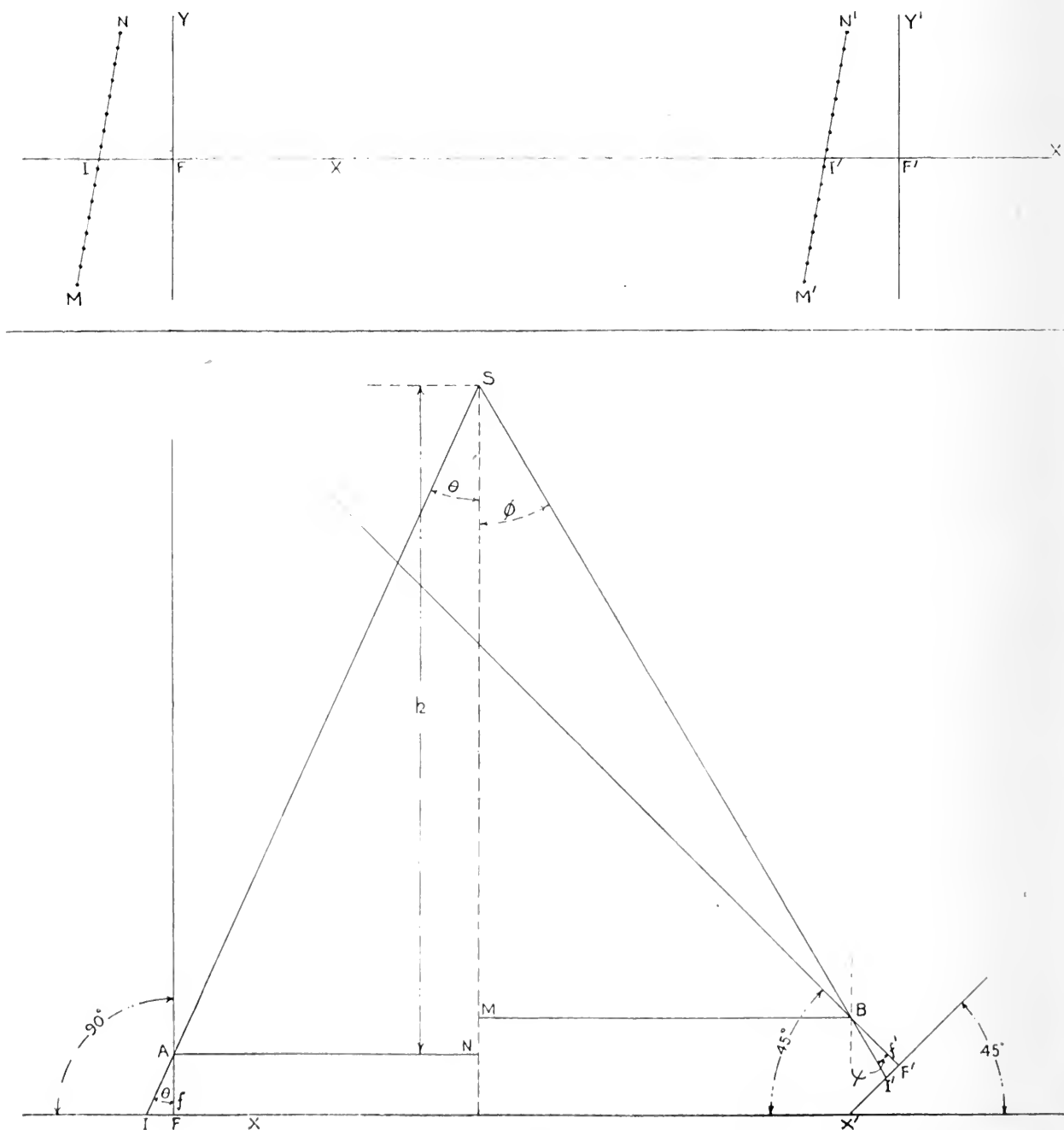


FIG. 8.

focal length and very carefully calibrated optically. In the case of each lens, a plane dead-level slate slab is adjusted so that its surface coincides with the focal plane of the lens. On each of these surfaces through the focal point of the lens are drawn two mutually perpendicular straight lines, one of which is the trace on the surface of the vertical plane containing the axes of the two lenses. In the upper part of Fig. 8 these axes are shown, F being the focal point of A and F' the focal point of B . The image of an object crossing the field of view of both lenses will obviously cut the axes Fx and $F'x'$ simultaneously, and from the measurements of the intercepts of the image on Fx and $F'x'$ the time height of the object can be found by means of ordinary trigonometrical equations.

Thus, if L feet is the distance between the lenses, and one lens through the contour of the ground is Y feet above the other h , the height of the object

$$= \{ L + Y \tan (45^\circ - \phi) \} / \{ \tan \theta + \tan (45^\circ - \phi) \}$$

are calculated from observations on the surface charts since $\tan \theta = FI/f$ and $\tan \psi = F'I'/f'$.

If an aeroplane flies along a straight horizontal path over the system so that the path can be traced in the table charts of both lenses and the rates at which the images travel measured, the true ground speed of the aeroplane at that height is calculated from the height and focal length, *i.e.*, time ground speed $= hv/f$ where v = rate of travel of image.

In practice the observers in the camera huts are in direct communication by telephone, and in parallel with telephone circuit is placed the electric seconds pendulum circuit already described in connection with the ground speed course, thus enabling observers to hear synchronous second "clicks."

The pilot flies the aeroplane straight and level at a height between 3,000 and 5,000 feet, according to the maximum speed, in a direction as near as possible at right angles to the plane containing the optic axes of both lenses. The observers in the camera huts plot in the path of the image by dotting its position at intervals of one second as shown by MN and $M'N'$. To enable the wind speed at that height to be calculated Very smoke cartridge is fired, the path of the smoke cloud image being dotted in by a second observer. Similar flights are carried out at various air speeds. The ground speeds can thus be calculated; also time speeds by correcting for the wind. The pilot takes the readings of A.S.I. aneroid and atmospheric temperature during each run. The correction for the air speed indicator is then deduced as in the case of calibration over the ground speed course. Fig. 9 shows a copy of a chart from the camera obscura, but with lens vertical.

(4) Climbing and Speed Test.

Flight tests to determine the climbing qualities and speed of an aeroplane are invariably carried out together, the procedure being as follows:—The aeroplane, loaded to the specified total weight for the test, is climbed at full throttle at the best climbing speeds already found, up to the service ceiling (100ft. per min.) or 17,000 to 18,000 feet, if this is lower than the service ceiling. In cases of scouts, higher altitudes are of course necessary and due provision must be made for oxygen and heating apparatus. Having reached the end of the climb, the aircraft is flown level at a series of heights on the descent, which should not be too rapid as to cause undue cooling of the power system. The required data are obtained from (1) pilot's and observer's readings, and (2) recording instruments. First dealing with the readings to be noted, it will be agreed that for a single-seater scout aeroplane they are rather formidable and readily show one of the reasons why a test pilot requires training.

(1) Atmospheric Temperatures.

These are read from a strut thermometer fixed clear of any propeller slip-

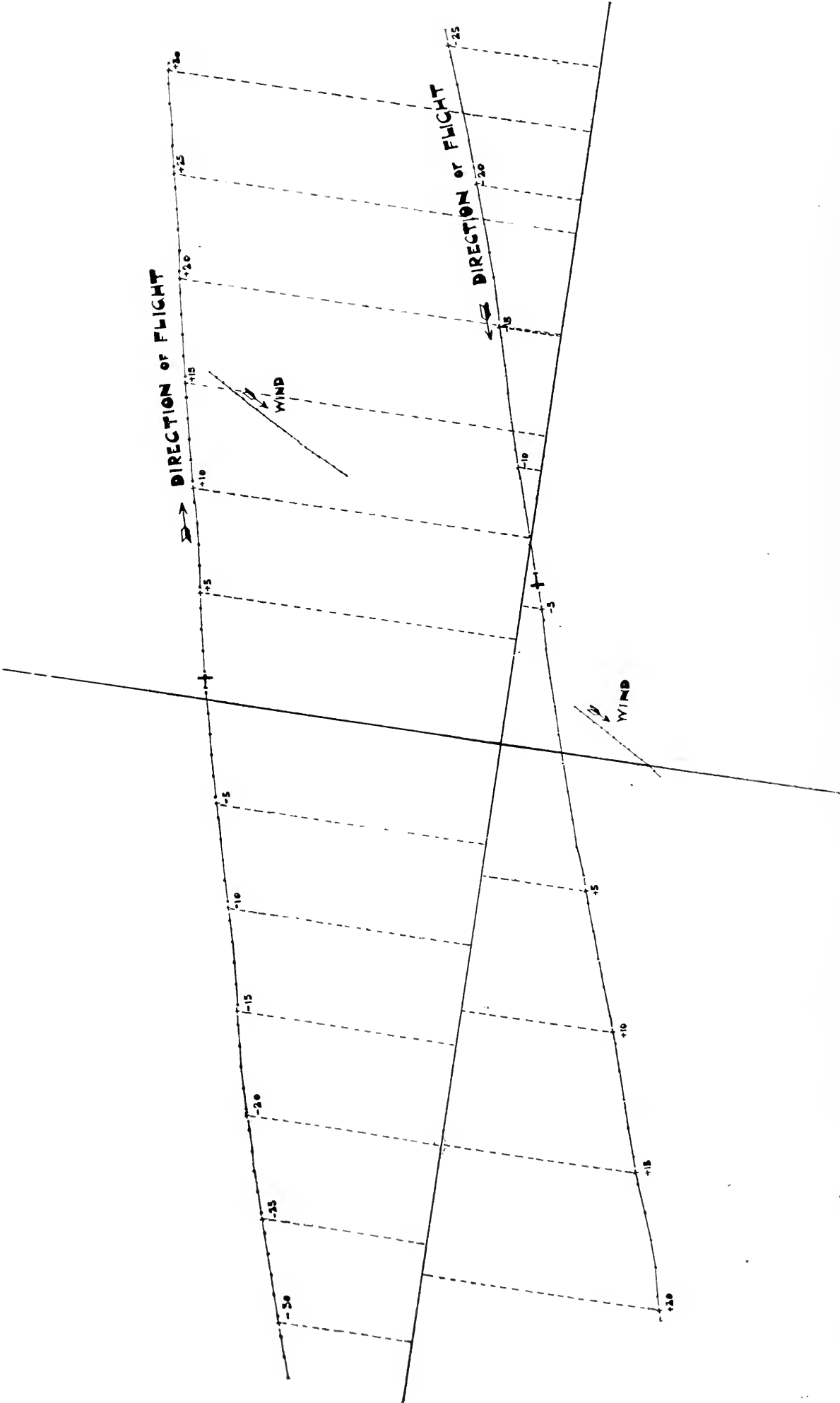


FIG. 9.

stream, or from a vapour pressure thermometer, which allows the capillary tube to be led to a dial in the cockpit. The advantage of the latter is clear—the pilot or observer does not have to move his head and re-focus his eyes from the other instruments in the cockpit. Also a larger scale is possible and observation errors are reduced to a minimum. Readings are taken from ground level and every 1,000 feet up to the end of the climb, also at the level speed heights on the descent. Calibration of these thermometers is somewhat difficult for the low readings, and cannot be done with the ordinary plant available at an aerodrome. Lag, of course, is important in the case of fast-climbing aeroplanes; if a strut thermometer is used and we can only approximately allow for this by

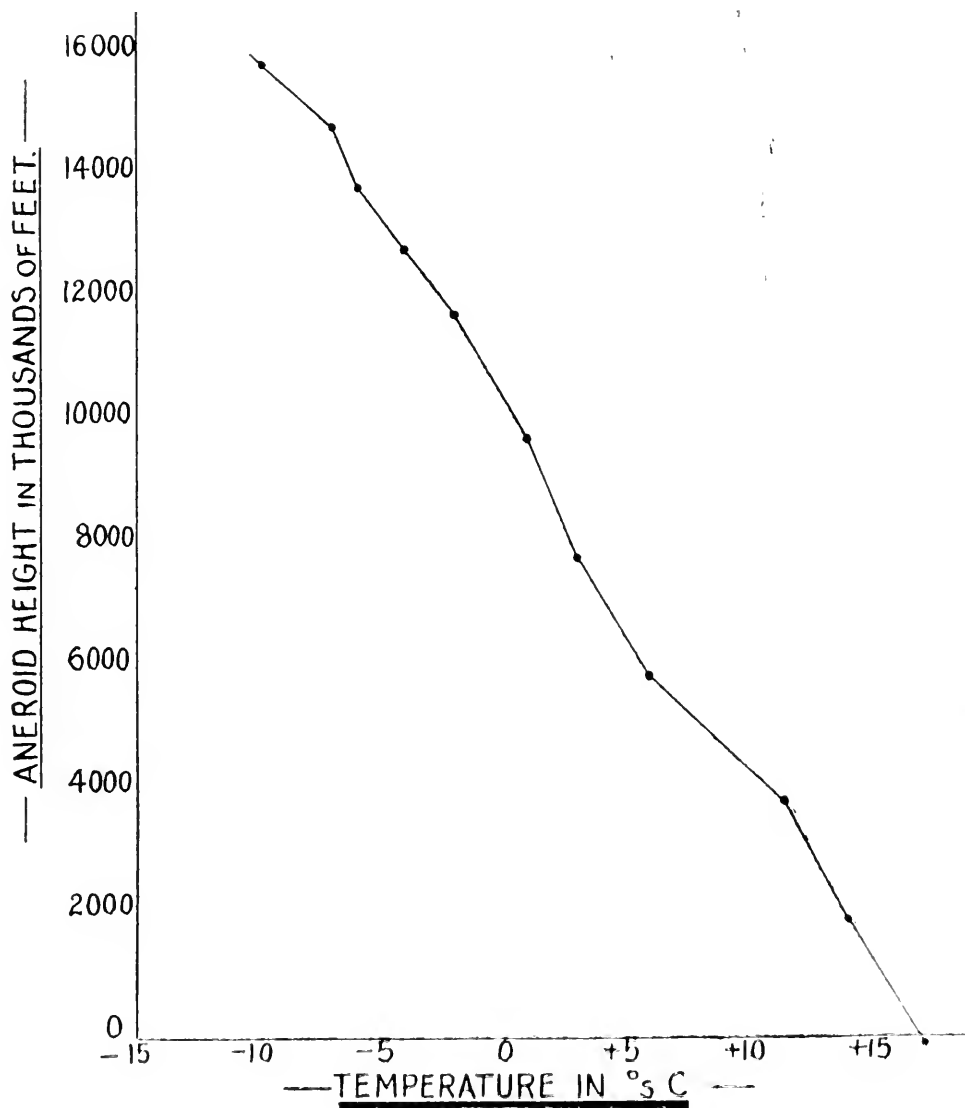


FIG. 10.

D.H.9a 400 Liberty. Temperature Reading for Test.

observing the rise of temperature when flying level at the end of the climb and noting time until steady, the lag is rarely more than 0.5 of a degree. An alternative way of noting temperatures on a descent at the same rate is open to the objection of general change in temperature of the atmosphere affecting the results; also it is practically impossible to guarantee passing through the same atmosphere. Fig. 10 shows the temperature readings of a test climb plotted against aneroid height.

(2) Aneroid Height.

The heights every 1,000 feet are noted against stopwatch. The instrument used is the standard R.A.F. altimeter calibrated before and after the trials in a vacuum chamber against the standard scale mercury column. As the aneroid is used as a pressure instrument, this means that the height scale is fixed and, according to the variation of the barometer, the reading above or below should be noted, although this can be checked against the ground recording barometer reading at the time of beginning the climb.

(3) Air Speed from the A.S.I.

The standard R.A.F. pattern A.S.I. and pitot head is used calibrated for instrument errors and pitot corrections as previously described. Readings are taken every 1,000 feet in the climb and during level speed tests. These latter

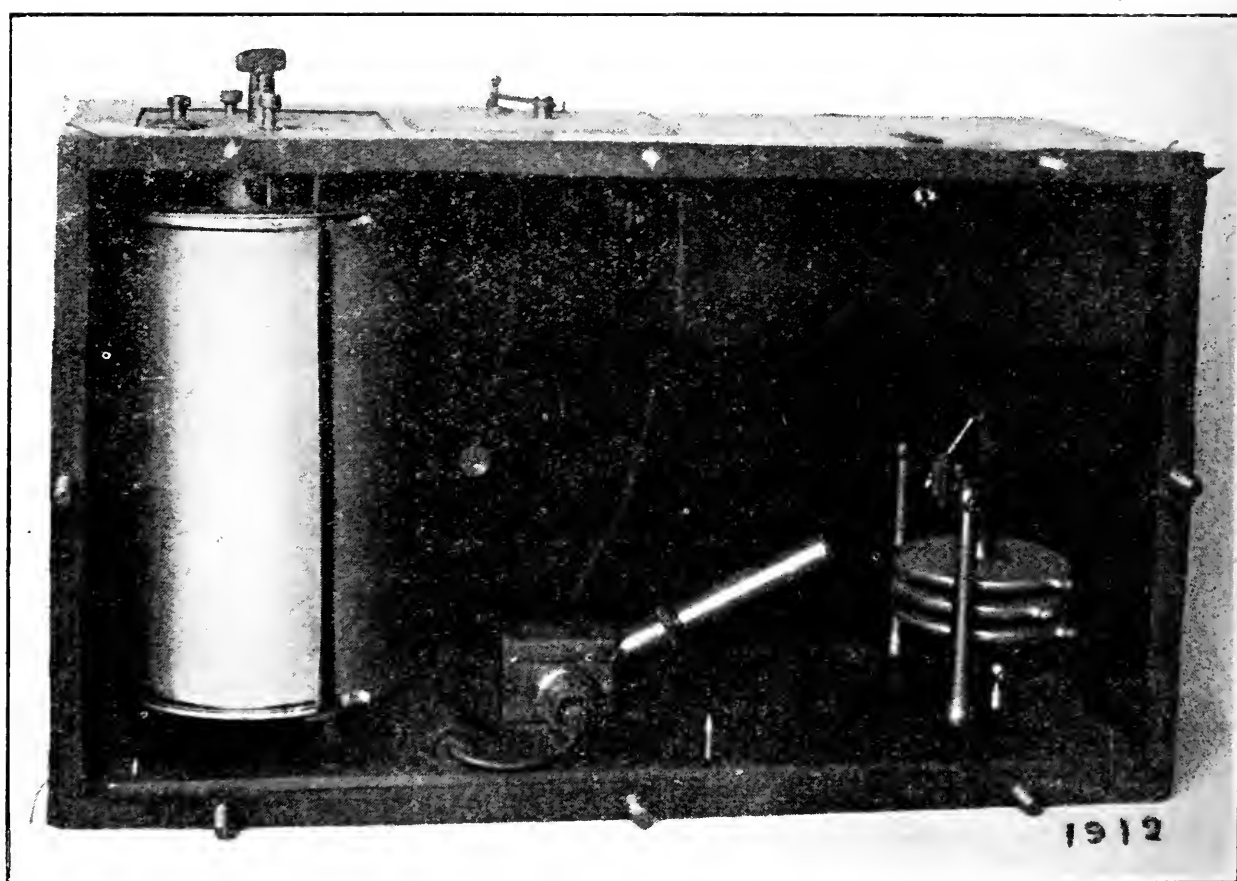


FIG. 11.

should be of not less than three-minute duration, preferably longer, and must be level. A check on this will be observed on the recording instruments which will be described later. To help the pilot, the Wright Bubble Statescope is fitted. This extremely useful instrument is very necessary when a far horizon or clear distant cloud edge are not visible. In order to counteract any air currents with a slight fall or rise, the climb should be carried out in a large diameter spiral path of the order of five miles.

(p) Other readings are taken every 1,000 feet and during level speeds are: Engine r.p.m., radiator temperature, oil pressure, position of radiator shutters or blinds or of radiator if of hinged type. This latter is recorded by noting control position on a scale marked to correspond with definite positions of the shutters on radiator, care being taken for pressure to be applied to the shutters to take the place of wind pressure in actual flight.

At the present stage of instrument development, recording barographs and air speed indicators are the only two which can be used with any degree of accuracy. Recording air and radiator thermometers and revolution indicators are still only in the experimental stage. At the same time, I am a firm believer in both observed and recorded readings, as even the most reliable reading instrument may fail during an important part of the tests.

Two types of recording barographs have proved satisfactory for aeroplane testing—the small pocket design by Richard of France and the box variety, giving a much larger scale. The scale of the pocket size is usually 5.5 cms. for 20,000 feet with time 2.3 cms. per 30 minutes. The total size of the instrument is 5in. by 3½in. and of chart 3½in. by 2½in. So it is quite possible to carry several, usually three, on a climb. As the pen movement is slow, in order to prevent a thick line being recorded due to the ink running, etc., the clockwork

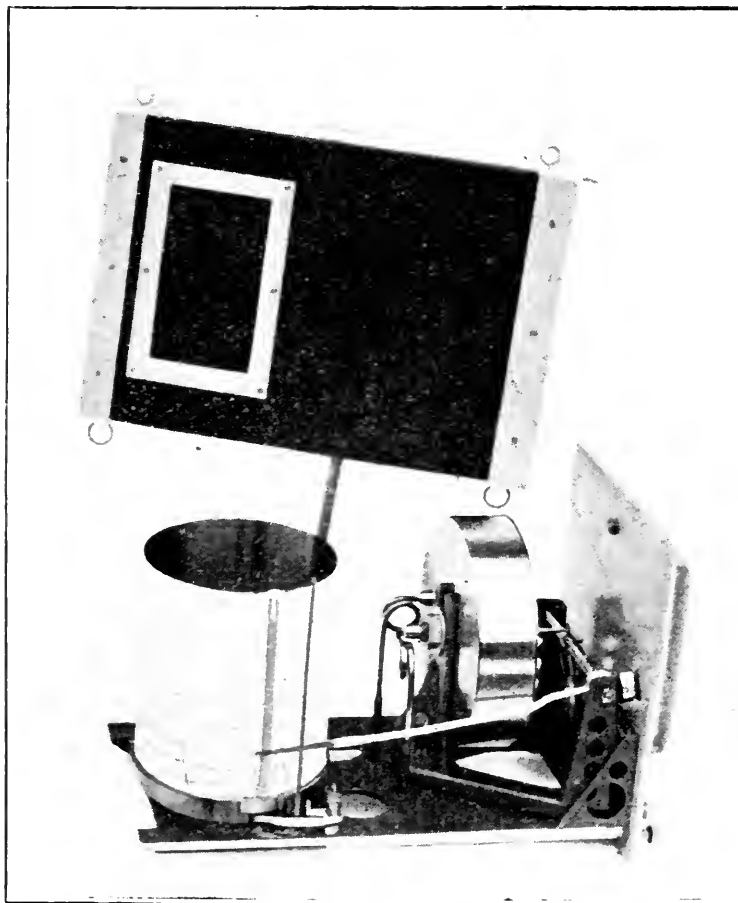


FIG. 12.

raises the pen once every 7 seconds; thus the recorded line is really a series of fine dots. The height scale is calibrated before and after the test climb, ascending and descending. Other calibrations include clockwork test by running for 30 minutes and noting time scale; and pen swing in case the chart has not been placed in position dead true. Extremely accurate readings can be obtained from these charts by photographic enlargements.

The larger type of recording barograph, giving consequent greater accuracy of observations, presents no special features and follows the design of the usual recording atmospheric barometer. Apart from the pocket Richard, all recording instruments are necessarily subject to vibration, which must be guarded against by suitable shock-absorbing suspension or mounting. All also are subject to backlash, and the link motion has to be constantly examined and adjusted. To

overcome the latter defect, an interesting instrument has been designed by Prof. S. Smith (of Alberta University, Canada) when a Captain, R.A.F., on the Technical Staff at Martlesham Heath. This is shown in Fig. 11. The principle consists of a spot of light being focussed on to a small mirror suspended axially and moved by the rise and fall of the aneroid boxes. The reflected light forms a record of this movement by shining on to a photographic sensitised paper revolving on a drum. The absence of the usual complicated link motion, pen friction and bearing friction practically eliminates all backlash and reduces lag to a minimum.

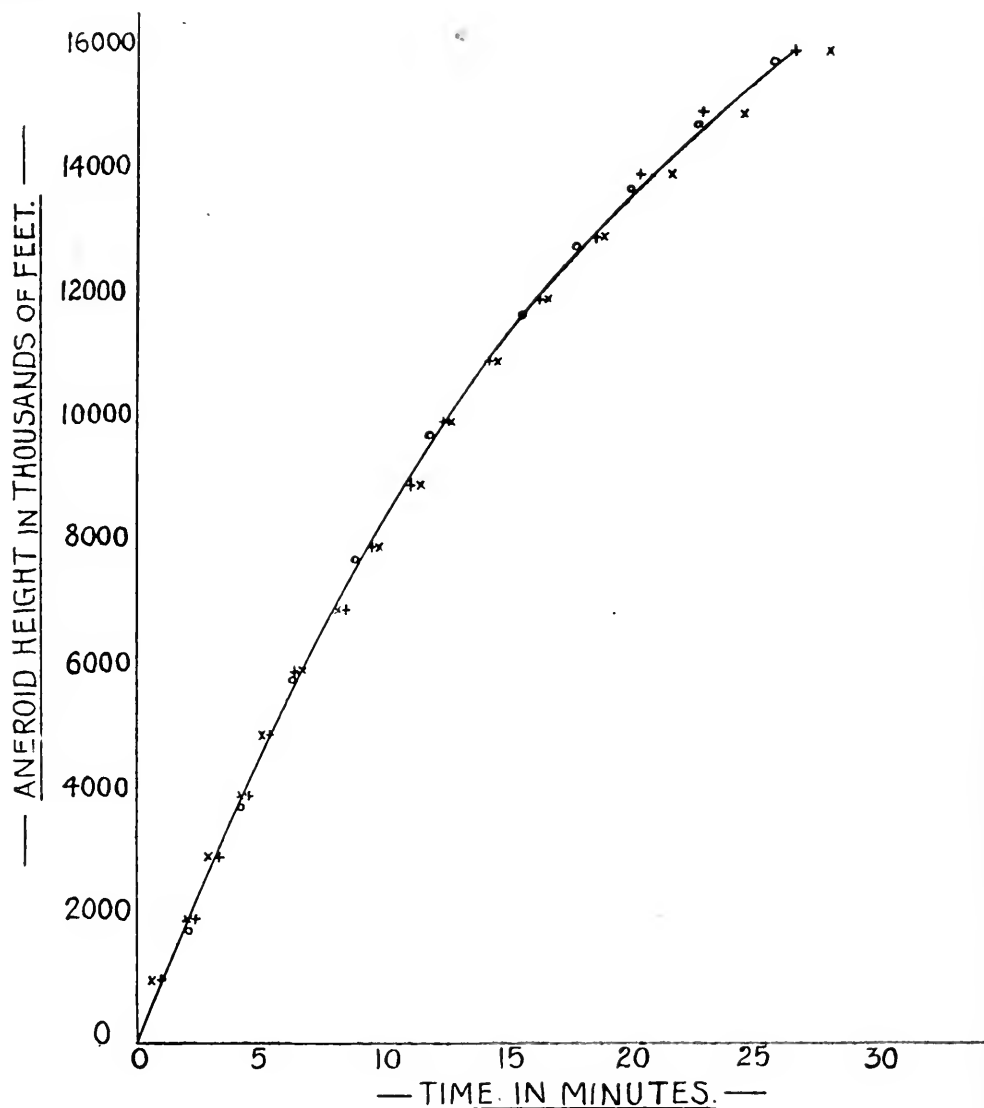


FIG. 13.
D.H.9a 400 Liberty. Aneroid Height—Time Curve.

Recording air speed indicators are constructed on the same principle as the recording barograph, the recording mechanism being operated by movement of the diaphragm of the differential pressure box. An example of this type is shown in Fig. 12, designed and constructed by Messrs. Munro.

Having obtained all the necessary data from the flight tests, the reduction to standard atmosphere is a matter of routine calculations.

The first stage is to plot aneroid height against stopwatch time and recording barograph heights against their time. It is usually found all these agree very well, and a mean curve is drawn which will average all errors of observation. Such a curve is shown in Fig. 13. From this, aneroid rates of climb are obtained by taking tangents at every 1,000 feet. This rate of climb must then be multiplied by the aneroid correction factor corresponding to the atmospheric temperature

recorded at that height, thus giving a time rate of climb. Using the density curves previously described, the standard heights, corresponding to the aneroid height (or pressure) and temperatures are read off. True rates of climb are then plotted against standard height as shown in Fig. 14, which is typical and gives the results of three test climbs worked out in this manner. The mean rate of

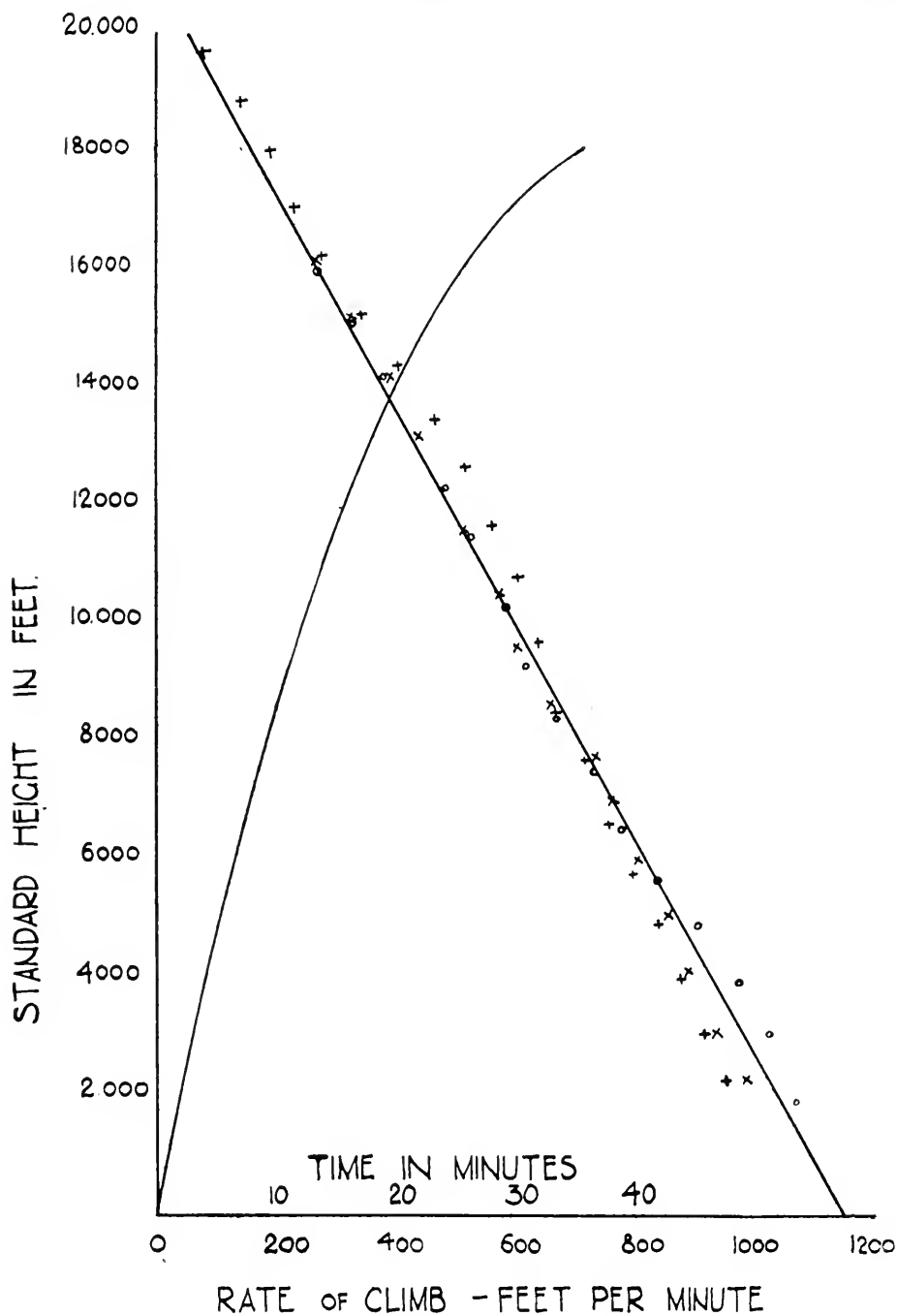


FIG. 14.

D.H.9a—400 Liberty. Rate of Climb and Time to Height.

climb curve is in nearly every case a straight line. The ceiling is given by its projection to the height ordinate. By simple integration a formula is developed for the time T to any height h .

$$T = 2.3 \tan \theta \log C / (C - h)$$

where C = ceiling height, θ = angle of slope.

If the rate of climb curve is not a straight line, possibly curving away slightly at the top or bottom, the reciprocals of the rate of climb are plotted for

each thousand feet, and a mean curve is drawn through the points obtained. The time to any height is then given by the area enclosed by the horizontal ordinate at this height. From this time to height curve all particulars of climb for any height can be read off as required.

The reduction of A.S.I. observation or self-recording instrument readings to true speed is straight forward, as the speed course correction factor has already been obtained, also the standard height and density. The A.S.I. standard

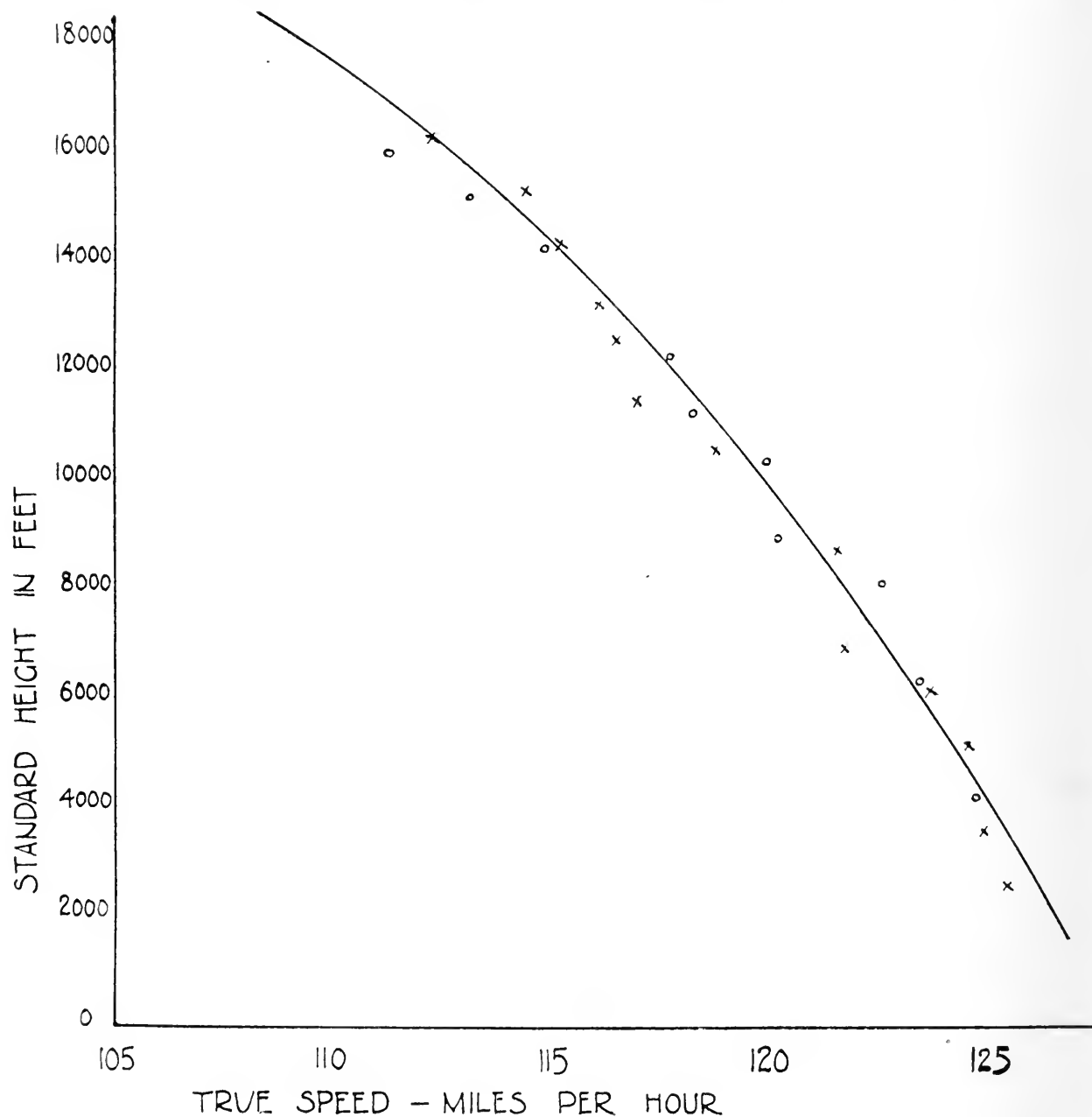


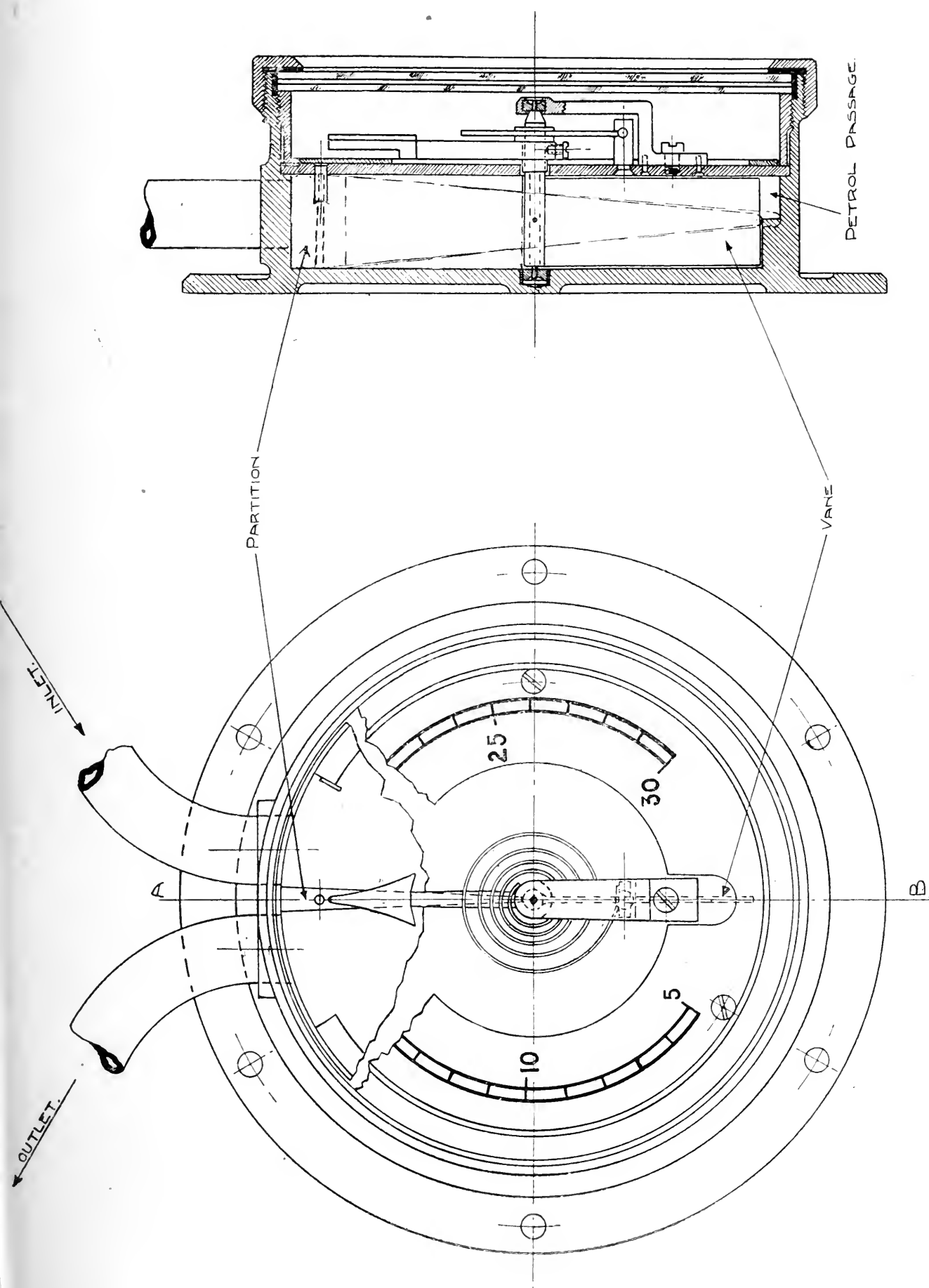
FIG. 15.

De H.9a 400 H.P. Liberty. True Speed at Heights.

density is .004 less than our adopted standard density of 1.225 kilo. per cubic metre, but this is not sufficient to affect the results appreciably. Thus it is only necessary, after applying the correction factor, to divide by the square root of the density at the height in question to obtain the true speed.

True speeds are plotted against standard heights from three or more test flights, and a mean curve drawn from which speeds can be quoted, possible errors due to piloting, weather conditions and observations being averaged.

Figure 15 shows results of three tests and the final curve.



SECTION THRO' A-B

FRONT VIEW (BEZEL AND WINDOW REMOVED)

FIG. 16.—Petrol Flourmeter.

(5) Miscellaneous Tests.

Consumption Trials.—Fuel consumption of aircraft is most important from a military point of view. In civil aviation the range of an aeroplane is not cut so fine, the bench tests of an engine giving sufficient data for determination of safe flying distance without replenishment of fuel.

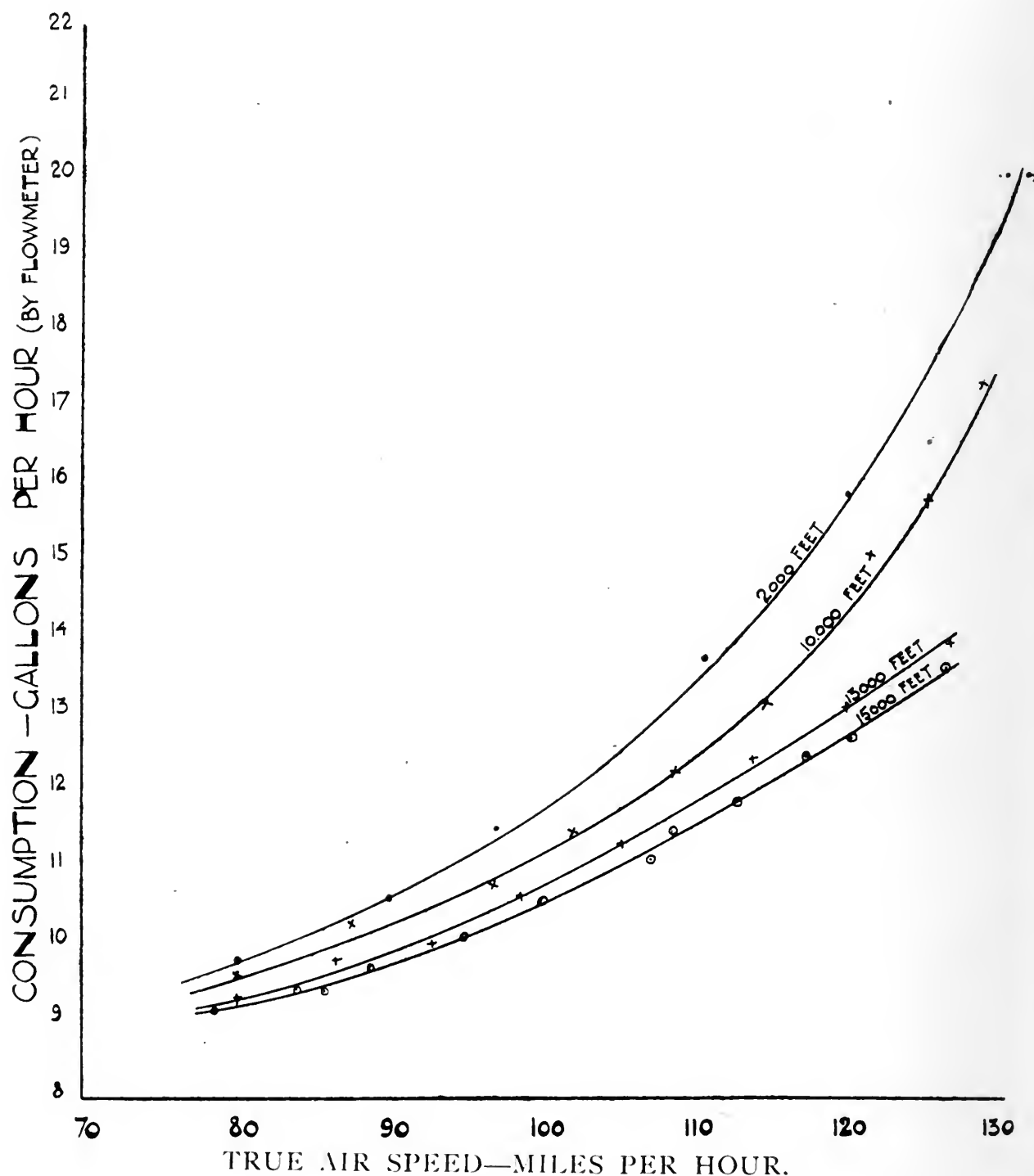


FIG. 17.

Series of Consumption Curves. 300 h.p. Hispano Suiza.

In the case of Service aircraft, however, it may be necessary to carry out bombing or reconnaissance duties at limit distances. Actual consumptions are then of great help in preparing for such duties. Take the case of a long-distance bombing aeroplane, the consumption on the outward and homeward journeys to the objective varies considerably, with height, load, and speed. If,

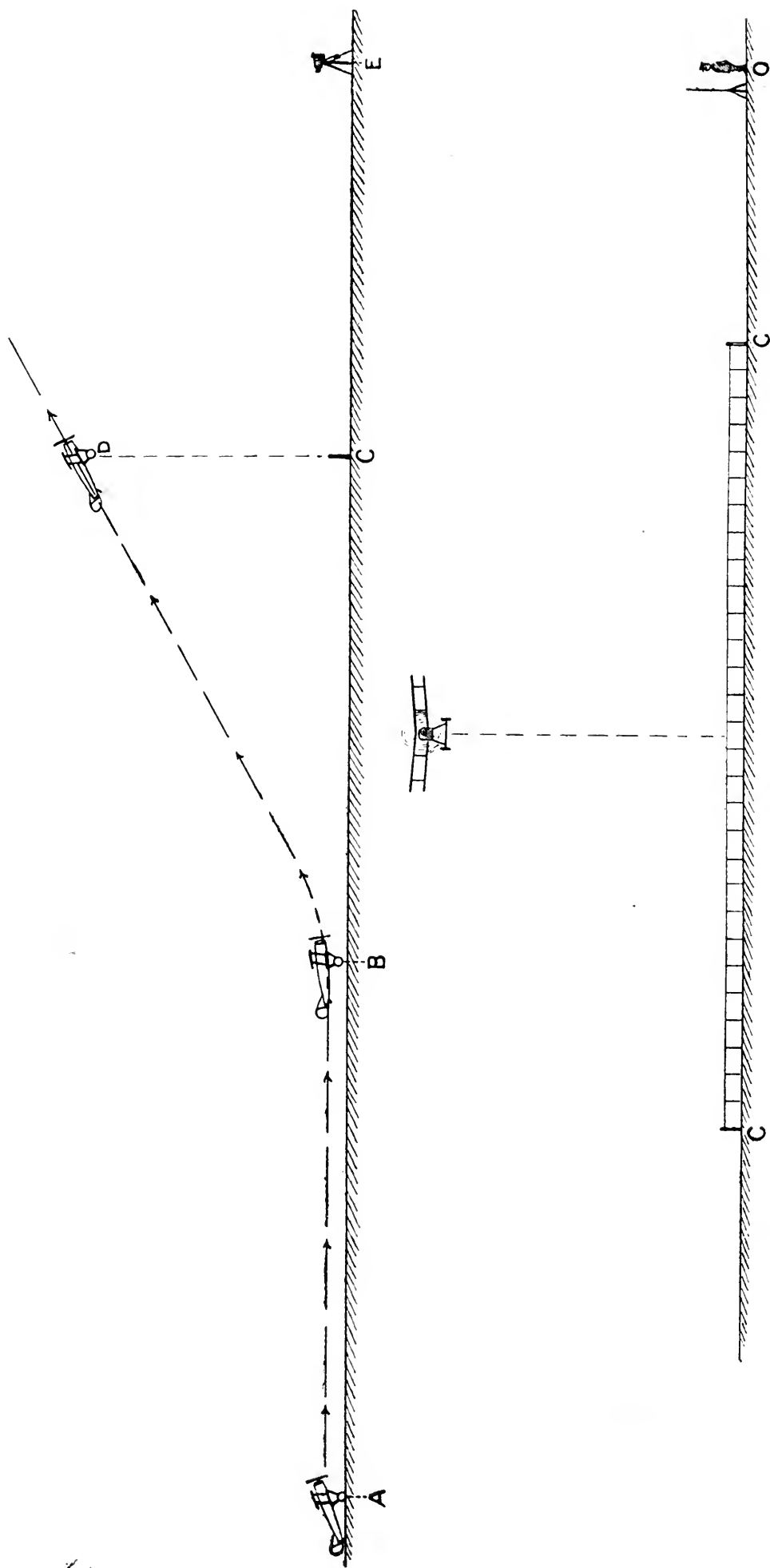


FIG. 18.—*Getting-off Tests.*

therefore, one knows, for instance, the most economical speed and consumption of the aeroplane, (1) fully loaded, (2) medium load, *e.g.*, no bombs and half fuel; (3) light three-quarter hour's fuel, at various heights, it is possible (subject of course to meteorological conditions) to plan the whole flight on its most economical basis.

Consumption trials to give this data are therefore straight level flights at various air speeds (usually five, varying from slowest speed to fastest speed) at suitable heights, say 5,000, 10,000 and 15,000. Each test must be of at least five minutes duration to enable the power unit, and also the instruments, to have settled down to the change. The actual consumptions are taken by a flow-meter, which can be calibrated to read direct gallons per hour or preferably lbs. per hour, so that variation in specific gravity of the fuel can be allowed for. One type is shown in Fig. 16.

This consists of a circular passage for the flow of petrol, which gradually increases in size from the in port to the out port. The pressure of this flow moves

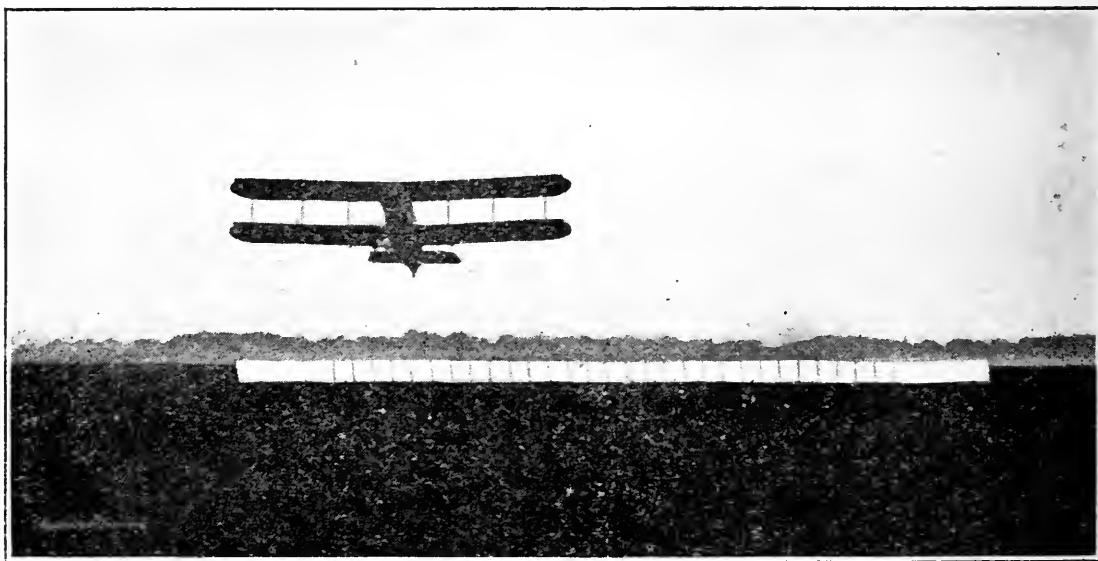


FIG. 19.

a light vane fitted to a central axis and rotating against the action of a coiled spring. The farther the vane moves, the larger the opening.

The same principle is adopted in the gravity type flowmeter, in which the graduated passage is obtained by fixing a taper inside the tube, the flow raising a ferrule against gravity.

Both instruments are liable to many errors in actual flying, the difficulty being to obtain steady and consistent readings with accuracy.

Consumption curves from results obtained by this type of flowmeter are shown in Fig. 17.

Getting off and Landing Tests.—The performance of an aeroplane with respect to its getting off and landing powers, assumed importance with the development of civil aircraft after the war. This was officially recognised, and special tests were incorporated in the schedule of the Civil Aviation Trials of 1920, held at Martlesham Heath. The methods then devised for the tests have now been adopted as part of standard performance trials of any aeroplane except scouts and high-powered two-seater fighters. All these tests depend so much on the wind that they are not attempted in any wind over 5 m.p.h.

Getting off Tests (Land).—The problem was to obtain the height of the aeroplane to an accuracy of 0.5 of a foot at a definite distance away from the starting point, the idea being that the aeroplane was supposed to be taking off either from a forced landing, or a very small aerodrome with trees, houses, or other obstacles which had to be cleared. The arrangement is best seen from Fig. 18.

Here CC is a canvas screen about 3ft. deep and 100 ft. long, marked off with narrow black strips every 3ft. The scale side faces a camera E, the lens centre of which is levelled on to the base of the screen, *i.e.*, ground level. The shutter of the camera is electrically released by an observer O stationed in the same line as the screen at such a distance that he can sight an aeroplane as it passes over the screen. From the scale CC it is thus possible to determine the height of the aircraft as it passes over the screen by measuring up the photographic negative.

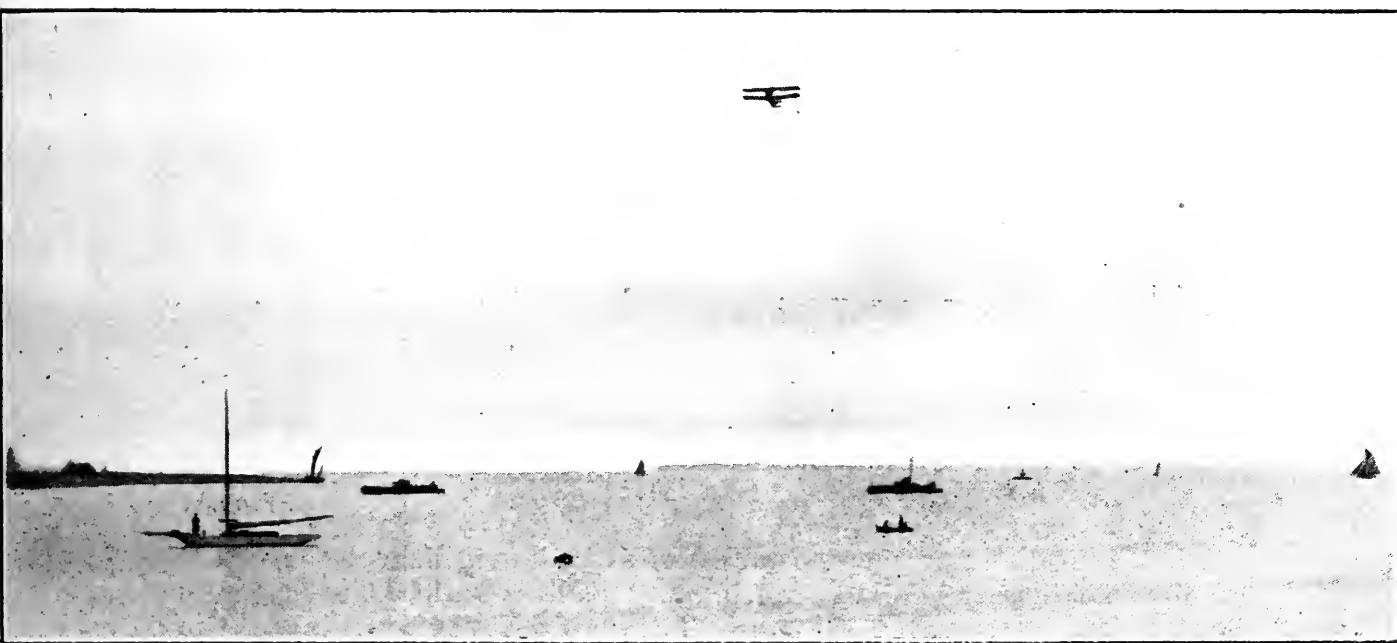


FIG. 20.

If this is done with a travelling microscope, extreme accuracy can be obtained. If the ground is suitable between A and C, it is possible to spot the point of take off from the wheel tracks, thus affording further data as to slope of climb in taking off. One point requires special attention, the lag between the tapping key of observer O and actual release of the shutter must not be large. It can be measured by taking a photograph of a swinging pendulum, using the actual apparatus and length of cable. In practice it was found that pressing the key just as the front of the aircraft appeared in the sight gave an actual image of about the centre passing over the screen. Fig. 19 shows the "Westland Limousine" passing over the screen during trials.

Getting off Tests (Sea).—The same principle is adopted, but the same degree of accuracy is not obtained. The scale is represented by two mark boats, anchored a definite distance apart. In line with these is the observer and sight, who has to be on shore or a pier for steadiness. By means of a signalling lamp, the instant the flying boat or seaplane passes over the scale line is flashed to the recording camera, which must also be on shore or a pier. It will be seen that more errors are liable than in the case of testing aeroplanes, but as results are only for comparative purposes and not for clearing a definite object, this does

not matter. Fig. 20 is a photograph of the Vickers "Amphibian" undergoing a test in this manner.

Landing Tests.—This resolves itself in the measurement of the distance required for the aeroplane to pull up dead or slow enough to turn after clearing an object of a definite height. It is obvious for test purposes these objects must not cause any obstruction to flying, in case the pilot flies below test height.

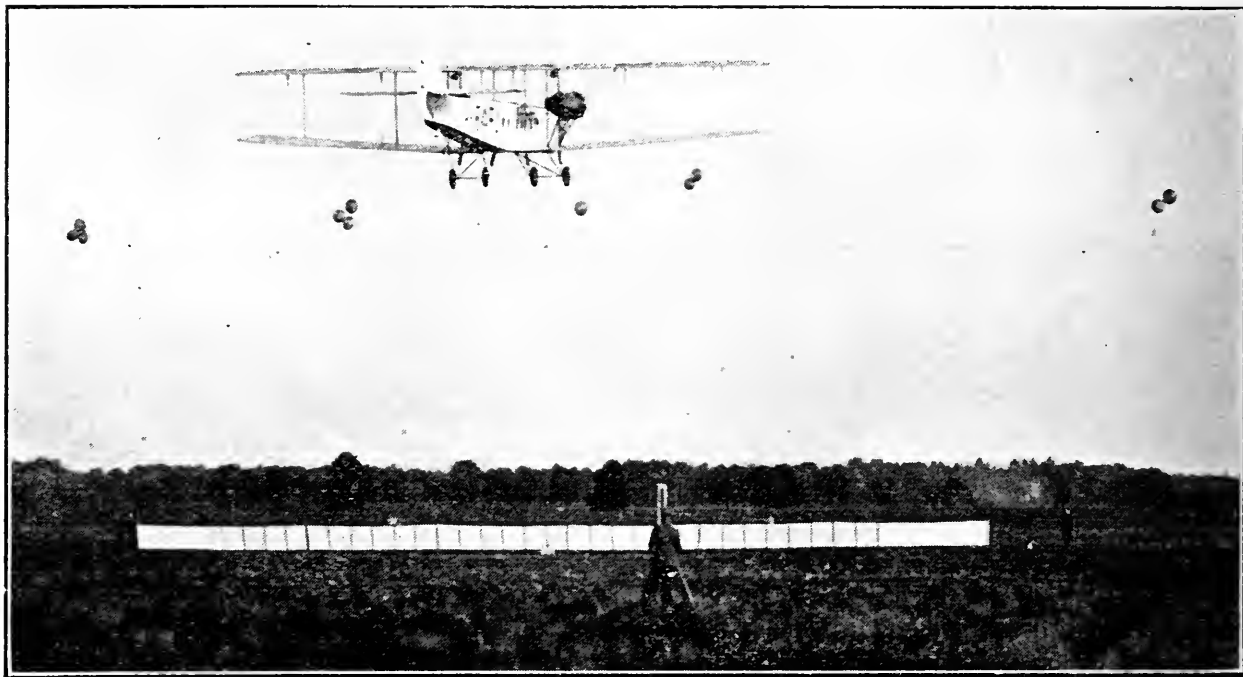


FIG. 21.

To indicate this imaginary obstacle, small hydrogen balloons were floated at the required height, each being on a minute windlass with a fine height line and weight. It has been proved that there is no risk if the pilot does fly into the balloons or twine. Having cleared the balloons, the actual point of pull up must be spotted by observers. To save long measurements the aerodrome, in the case of the civil trials, was accurately surveyed and three circles marked out with numbered calico strips pegged on the circumference every five degrees. It was then only necessary to refer by measurement to two or three of the strips nearest to the observed point. This test also affords means of trying out braking devices. Fig. 21 shows the Handley Page clearing the line of balloons before landing.



PROCEEDINGS.

EIGHTH MEETING, 57th SESSION.

A meeting of the Society was held in the rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, February 16th, 1922. In the unavoidable absence of the Chairman, Lieut.-Col. O'Gorman, Major-General Sir W. S. Brancker presided, and introduced Squadron-Leader C. F. A. Portal, D.S.O., M.C., who is an instructor at the Cranwell Cadet College, in Lincolnshire.

Squadron-Leader PORTAL then read his paper on

METHODS OF AEROPLANE FLYING INSTRUCTION.

I must begin by confessing that when I received the kind invitation of the Royal Aeronautical Society to read a paper on the methods of aeroplane flying instruction, I had grave doubts as to whether I could make it either informative or interesting.

In the first place, by comparison with others on which papers have been read here, this subject seems "cut and dried." I do not mean that flying instruction has reached such a pitch of excellence that further improvement is impossible, but that as far as the Royal Air Force is concerned the present methods are stereotyped in certain orders which the service instructor has to obey.

Secondly, I fear that a great many of those present know almost all that there is to be known on the subject, and I must ask them to be patient when I travel laboriously over ground which is very familiar to them.

I shall confine myself as much as possible to the practical side of the question as it presents itself to the instructor to-day. I expect that much of interest might be said on the historical, theoretical and medical aspects of the subject, but I fear that if I ventured to leave the firm ground of modern practice I should speedily find myself hopelessly bogged.

In the year 1915 (I cannot speak from personal experience of earlier times) there were two types of school at which the pupil might, if he were lucky, learn to fly. A brief description of the methods used at each will help us to realise the improvement which has taken place during the last six years.

The more advanced schools had dual control aeroplanes, usually Maurice Farman's, but in most of them the duplication of the controls was very primitive and inefficient. The instructor generally sat in the pilot's seat with the pupil behind him. There was no standard system of teaching, and each pilot went about the business in his own particular way.

What he generally did was to fly round with the pupil's hands on the controls until the latter had some idea of the movements necessary to execute turns and had visualised the correct position of the aeroplane under the various conditions of flight. The best instructors then put the pupil in the front seat where he could see ahead, work the rudder properly and use the instruments. Great importance was attached to the air-speed indicator, and the different speeds for taking off, climbing, level flight and gliding were learnt by heart. After a few landings (done by the instructor as a rule, the pupil's hands being on the controls)

and still fewer words of advice on the management of the engine, the time arrived for the first solo flight.

These "first solos" were often terrible sights. The responsible instructor had, of course, to watch the proceedings, but everyone else usually retired out of sight. Well they might, for any small misfortune (from the sudden appearance of a lorry on the road across the aerodrome to the awakening of a dormant earwig within the pitot tube) was enough to cause disaster.

Some instructors were cleverer than others and taught their pupils better and more quickly, but I do not think that any two of them worked on the same lines. A great many, and among them were the leaders of the great "Instructional Revolution" of 1916-17, were themselves perfect pilots on the aeroplanes of the time, but not one of them had formulated any proper system of teaching.

Whatever success attended the pupil taught by the average instructor of the period depended on his ability to imitate. It was not until he went into the air alone that he began to acquire any real knowledge, and this often had to be bought at the price of several undercarriages. The experience and confidence of most pilots was limited, and in some cases the instructor occupied, throughout the dual control period, the seat from which the unfortunate pupil would be called upon to control the aeroplane on his first solo flight. Since the pupil's safety depended upon his ability to visualise the correct position of his aeroplane in turns, glides and landings, it is clear that a sudden change of view-point just before the first solo flight was a very serious matter.

There were at this time certain schools which taught on quite different lines. Here the pupil received a good deal of verbal instruction on the ground, but was from the first alone in the aeroplane. Beginning with an aeroplane fitted with an engine too weak to lift it into the air, he was encouraged to run about in it on the ground until he became proficient in the use of rudder and engine controls. He was then promoted to a more powerful mount, and gradually learned to perform "hops," "straights," and finally landings and turns.

There was probably more to be said for this method at the time than the modern instructor might suppose. The pupil sat in the same seat throughout, worked his own engine, and above all knew from the start that he must work out his own salvation. Though his methods might be unconventional, he rapidly gained confidence in himself. These advantages are only appreciated when the state of contemporary dual control is remembered; the greatest advantage which the dual control schools enjoyed lay in the fact that they were more independent of weather conditions.

Towards the end of 1916 came what I have referred to as the "Instructional Revolution." I hope I have succeeded in showing that the instructional methods of 1915 were, to say the least, far from perfect. The chief causes of inefficiency seem to have been, in the first place, want of confidence and experience on the part of instructors, and secondly, the absence of any real system in the methods employed.

The organiser of the new school which was to revolutionise the whole aspect of flying instruction appeared to base his system upon three facts, which up to that time had scarcely been realised. He maintained, rightly, that (1) A properly designed aeroplane could be safely put into any position provided that it was at a sufficient height to enable it to right itself and gather speed without hitting the ground, and that pupils should not be taught on craft which were not properly designed. (2) There was only one way to perform any manœuvre correctly, though it could be done incorrectly in many. The habit of flying correctly ensured safety under all conditions. (3) The movements necessary to perform any manœuvre correctly were capable of clear analysis and simple explanation.

Anyone who has learned to fly since 1916 probably thinks that the knowledge of these facts is as old as flying itself, but I myself remember being told by the best instructor in my station that it would be unwise to stall an Avro as one never could be sure of getting out of the nose-dive; I also remember, in 1916, seeing an Army Commander and several senior R.F.C. officers who had come miles to witness a display of "stunting" by one of the French "Aces"; everyone present thought the performance wonderful, and the pilot was overwhelmed with congratulations, though what he did has been done in my presence by a pupil on his first solo flight.

The policy of the new "Instructors' School" was as follows. The staff was carefully selected from officers who were able to fly perfectly themselves and at the same time had the gift of being able to teach. A standard method of instruction was adopted, which has remained practically unaltered for five years and will be dealt with later. To enable pupil and pilot to communicate freely in the air a telephone was introduced, by means of which each movement could be explained and every fault corrected.

Now for the first time the young pupil had everything simply and carefully explained to him. Instead of having the control lever snatched from his hand whenever he made a mistake, he would hear his instructor speaking calmly to him and telling him what was wrong and what to do. Nor was the effect of the new system limited to mere proficiency in flying. With understanding came confidence and the gradual realisation that, provided the ordinary rules are observed, flying is as safe as any other form of locomotion. In an incredibly short time the leaven from the first instructors' school had permeated the whole service, leading to a vast improvement in flying ability and moral.

I will now try to describe more fully the actual method of instruction used. I should first say that the Avro with 100 h.p. Mono engine was adopted as the standard elementary training aeroplane at the end of 1916; though the system to be described was devised primarily for the Avro, it is applicable to almost any single-engined tractor.

The pupil gets into the back seat, is connected by telephone to his instructor, and is taken up to a height of about 1,000ft. He is first told that he must sit at his ease with his muscles relaxed, his heels on the boards provided for them, and his insteps touching the rudder bar lightly. Many pupils get into the habit of sitting rigid and immovable, like a criminal in the electric chair; this is not conducive to good flying, and should be corrected at the start.

The "patter" used by the instructor in the first lesson is something like the following, and may be taken as a specimen of the whole. Having explained that there are three controls operated by the pilot in flying, he continues:—

"When the control lever is pushed forward, the elevator is depressed. The air, striking the under side of it, raises the tail and depresses the nose." (Here he pushes the lever forward to illustrate.) "When the lever is pulled back, the elevator is raised; the air strikes the top of it, depresses the tail and so raises the nose." (Again the fact is demonstrated.) "When the control lever is pushed over to the right, the left ailerons are depressed and the right raised; the air strikes the under side of the left aileron and the top of the right ones, raising the left and depressing the right wing."

The use of the rudder is explained in the same way. I only give the above example to show the extreme simplicity of the language used and the fact that nothing is taken for granted.

To describe in detail the teaching of each particular manoeuvre would need several papers of this length. I will merely give an outline of the course, showing the order in which the subjects are most conveniently taken and the average time required for each of them.

The pupil has had the effects of three controls, used singly, explained to him. The next step is to give him entire control, telling him to keep the top of the cowl level with the horizon, the wing tips level with one another, and the nose pointing to some distant landmark. This is generally called "flying straight and level." At first the pupil can only remember to use one or two of the three controls at the same time. His wing tips may be level and his cowl on the horizon, but his nose will then swing round to the left. He corrects this with the rudder, but now his nose is too low; he pulls it up to the horizon again, only to find that he has let his left wing drop. This goes on for a few minutes, but generally within a quarter of an hour he is able not only to keep his course on a level keel, but to return to it after the pilot has disturbed it by a sudden movement of the controls.

The instructor avoids as much as possible any interference at this and all other stages, merely telling the pupil quietly what to do when necessary.

When the novice can fly straight and level satisfactorily, he is shown the climbing and gliding angles of the aeroplane, and is told to note mentally the apparent distance between the top of the cowling and the horizon in each case. He is shown both the proper climbing angle and also the maximum angle at which the aeroplane will fly, and has his attention drawn particularly to the diminished effect of the aileron control as stalling point is reached. This concludes the first lesson, the time occupied being about half an hour. Pupils rarely derive any benefit from the last part of a longer period than this.

The next lesson consists of revision of the first one and demonstration of the way to make a 45deg. turn. As a rule only two turns are taught, one with a bank of 45deg. and the other nearly "vertical," say about 80deg. Three points should be explained on the ground before this lesson begins. First, that the use of each control is to turn the aeroplane about a certain axis, whatever may be its position with relation to the ground; secondly, that as the outer wing travels faster on a turn than its fellow, it will tend to rise; thirdly, that the nose of the aeroplane will tend to rise on a left-hand and drop on a right-hand turn owing to the gyroscopic effect of the engine.

Once in the air, the novice will forget this, but he should be told it notwithstanding. The proper combination of the controls necessary to make a sustained turn with the cowl on the horizon and the diagonal bracing wire in the centre section horizontal is not, as a rule, very quickly learnt; three lessons of half an hour each are generally necessary. The pupil is next taught to turn on the climb and glide, for which one lesson is usually enough; the principle is the same as for ordinary turns and it is only necessary to use the elevator and rudder rather more coarsely in gliding to compensate for the absence of slip-stream.

The two following lessons may be devoted to steep turns, and here again some trouble may be expected. It is not at all easy to make a steep left-hand turn accurately on an Avro 504K, and the pupil generally stalls repeatedly and may have his first experience of a spin; if this happens, the instructor merely tells him what to do to get out of it.

In the next three lessons the pupil is shown how to make loops, half-rolls and spins, and is taken quickly over all the ground which has so far been covered.

Up to this point about five hours have been spent in the air, and the novice should now be able to execute accurately all the manœuvres of ordinary flying. He has been taught up to now to regulate his movements almost entirely by the position of his cowl with regard to the horizon, deriving also a certain amount of help from the "feel" of the controls and the intensity of the sound made by the passage of the aeroplane through the air.

In the lessons which follow he is taught no new manœuvres, but has to develop what is generally termed his "judgment." He has not only to learn

to take off and to land properly, but also to foretell accurately where his aeroplane will come to rest, to note the direction of the wind and to glide at the correct speed when he is too low to use the horizon.

Taking-off is generally learnt very easily, but landing is far more difficult.

At first the instructor explains the principle, and then does a few landings himself with the pupil's hand lightly holding the control lever. The difficulty which most learners experience is in estimating the height of their wheels from the ground; but even when this has been mastered the method of getting the tail down as the aeroplane loses speed takes a long time to teach, and there is often a tendency to abandon the rudder through over-concentration on the elevator. The ability to land well from the start is not found in more than one pupil out of ten, as a rule, and with one out of every five it may be necessary to continue the instruction on this subject for ten or twelve hours before any proficiency is attained. Most pupils can be trusted to land without accident after three or four hours' teaching.

The instructor's great difficulty is that he cannot here allow the pupil to see the effect of his mistakes. In turns, loops or half-rolls he has time to allow the pupil to correct his own errors, but when teaching landing he must frequently interfere in order to save the undercarriage from destruction.

When the pupil has learned to land reasonably well he is shown how to manage his engine, on the ground and in the air, and an hour or two is then spent with him in complete control, the instructor being there merely to prevent accident. After that it only remains to teach sideslips and cross-wind landings and take-offs and to let the pupil execute a few landings in fields near the aerodrome. At this stage he is generally able to assimilate his instruction very quickly, and as a rule not more than an hour is spent on these last subjects.

So, after anything from seven to twenty hours' dual or more, the pupil is at last sent up alone. The "first solo" is not nowadays the nerve-racking ordeal for all concerned that it was in 1915. The novice has been convinced in his own mind during the last two or three hours of instruction that he is quite capable of flying by himself, and always chafes considerably at any delay in sending him up alone. He almost always takes off well and lands passably; sometimes he spins and loops on his first flight. All that remains to be done is to give him a few minutes' dual each day as a "refresher," to watch him carefully for the development of faults in style and to correct them immediately by further dual control.

Further instruction is usually necessary in forced landings, and every means should be taken to improve the pupil's judgment before he is allowed to fly across difficult country. Two out of three accidents to newly trained pilots are caused nowadays by forced landings due either to engine failure or to loss of direction.

Much more time is, of course, spent on the dual control instruction of each pupil than was possible during the war, but the extra expense involved is very much more than balanced by the comparative rarity of "crashes." The average pupil in 1915 probably had about five hours' dual as against ten or twelve given to-day, but he probably damaged aeroplanes (to say nothing of himself) to the extent of several hundred pounds before he became proficient.

Accidents do still occur, as they will so long as man is human, but they are comparatively rare; as a rough guess one would have expected the 1915 pupil to break at least two aeroplanes completely, besides smashing half a dozen undercarriages; at the present time the average seems to be about eleven pupils trained for one aeroplane and four undercarriages wrecked.

On the chance that they may prove interesting I will give a few figures relating to two batches of pupils recently trained in the unit in which I am now serving.

The first batch had done no previous flying when their training began. The

average time spent in dual control with each pupil, up to the time of his first solo flight, was 15h. 35m. The shortest time required by any pupil was 10h. 35m., and the longest 32h. 10m. This last figure is quite exceptional, over 20 hours being spent in landings. The pupil was discovered to be suffering from eye trouble, and after a course at a specialist's became an excellent pilot.

All the pupils in the second batch had flown as passengers for about eight to ten hours before their training as pilots began. In their case the shortest time required for dual was 6h. 10m., the longest 16h. 25m., and the average 10h. 40m. The same instructors taught both batches, and the saving, with the second, of nearly five hours' dual per pupil can therefore only be attributed to "air experience" gained while flying as observers.

A great deal of trouble is taken in my unit to make the pupils conversant with the simple theory of flying before they begin their instruction. The uses of each control in all positions of flight, the effects of engine torque and slip-stream, the theory of landing and taking off properly are all carefully explained. The pupils listen most attentively and always remember what they are told until the moment arrives for them to go into the air. Then of course everything is forgotten, and not one pupil in a dozen believes that he has profited by what he has been told. Most of them think the reverse, and feel that they have been muddled and confused. As soon as the first excitement has subsided, however, the "theory" which has been taught them begins to assert itself and progress is much quicker. The instructor is also able to curtail his "patter" considerably, since the pupil knows most of it by heart before he goes into the air.

I will conclude with a few general observations upon instructors, pupils and aeroplanes.

The instructor must of course be a good and accurate pilot, but mere ability to fly well is far from being the most important of the necessary qualifications. He must love flying for its own sake; he must be patient, sympathetic and tactful; he must be able to analyse clearly his own movements in flying and those of his pupils; above all he must possess the power of imparting to them his own enthusiasm for flying.

The difficulties which instructors encounter in the temperaments of their pupils are many and various. The marked success of a particular teacher with all types of pupil is often attributable to his tact rather than to his knowledge or his energy. Some pupils are keen but clumsy, others have good "hands" but no "head"; one will be lazy and indifferent, another so highly strung and sensitive that a reproof snapped at him into the telephone will make him incapable of learning anything during the whole of the remainder of the lesson.

It is only by having his temper in perfect control and by the development of tact and a knowledge of human nature that even the best pilot can become a first-class instructor.

The first requisite in a pupil is the desire to learn to fly. He must also have a certain amount of mechanical common sense, good eyesight and perfect co-operation between brain and muscle. He probably requires a good many other qualities with long medical names, connected chiefly with the sense of balance and the power to judge angles and the rate of approach of the ground in landing. The pupils who learn most quickly and become the best pilots are generally those who are good at outdoor games and sports and keep themselves fit. The first two pupils to fly solo in the second batch referred to above were the only two who rode regularly to hounds. (The third, incidentally, was said to possess considerable knowledge of the turf!) Though good horsemen usually have good hands when flying, there is of course no reason why they should have good judgment or good eyesight. Almost anyone who leads a healthy life and has normally developed senses can be very easily taught if his heart is in the business.

The requirements in the aeroplane are that it should be reliable, simple and of suitable design. The cowl and front of the fuselage should be straight, and horizontal when the aeroplane is in flying position. It should have a high factor of safety, both mechanically and (if this is the right word) aerodynamically. The stalling speed should be low, and the feel of the controls should give early and ample warning of its approach; the smaller the space required to recover from a stall or spin, the better. The undercarriage must be strong and easily replaceable in case of breakage. Above all, the aeroplane must be sensitive in flight, and its controls must be well suited to one another. For example, heavy aileron and sensitive elevator controls do not go well together.

The Avro fulfils all these requirements and has the double merit of being very easy to fly, but not at all easy to fly well. Small errors are very well shown up without any risk of the pupil's suddenly losing control.

I am very well aware of the shortcomings of this paper, especially its incompleteness. The training of pupils on more advanced aeroplanes and the art of turning a pilot into an instructor are both outside the scope of my present duties.

I have confined myself to those aspects of the subject with which I am acquainted, and to description rather than history or speculation.

If I have laboured the obvious I can only say that I expected to have to do so; if I have omitted most of the points of interest, as I probably have in fact done, then there is every hope that we may at least hear a profitable and lively discussion.

DISCUSSION.

The CHAIRMAN, in opening the discussion, said he had a good many pangs of conscience, because he was the person responsible between 1914 and 1915, when the author had said there was no system and that the instructors did not know how to teach. He did not believe that when the war broke out there were in this country twelve men who knew how to teach; he doubted whether we had six. Those we had all taught on different systems. We really knew nothing about flying then, and had to encourage everybody to go on their own lines in order to learn what were the best methods. On top of that, when the Royal Flying Corps mobilised, they took every fit man to the front, and those left behind were either unfit for service at the front or were not considered sufficiently good pilots, and they had *force majeure* to be turned into instructors on the spot. He was always opposed to preliminary training, *i.e.*, training on an old Maurice Farman or box kite before a pupil was allowed to go to a fast machine. Curiously enough, he believed that every instructor in 1914 and early 1915 was dead against him. He insisted upon making experiments on Avros and B.E.2s, and in both cases the experiment failed because the instructors were not good enough. Then came what the lecturer called the "instructional revolution"—and he had omitted to mention the leader of that revolution, Smith-Barry, who was a wonderful pilot. He came spinning out of the clouds like an angel from heaven, so far as he (the Chairman) was concerned, and as the author had said, "in an incredibly short time the leaven from the first instructors' school had permeated the whole service, leading to a vast improvement in flying ability and moral." The service owed a great deal to Smith-Barry for what he had done. He was open to correction, but he believed that it was not until 1916 that a pilot—he believed he was French—discovered the proper and perfectly simple method of getting out of a spin, and until that was discovered it was impossible to do what Smith-Barry had done. He had learned it from the French pilot, and had put it into practice himself, and from that time we were miles ahead of the French or anybody else. Park's dive, he believed, was a case of spinning and happened in 1912. Somehow Park had got out of it, he did not think he knew how, and there had been a tremendous discussion on it, but he believed that Mr. C. G. Grey published the first

correct theory in "The Aeroplane," *i.e.*, one only had to push the rudder straight and put the nose down and the machine would come into control again. Speaking again with regard to training in the early days, the Chairman said that before the war they tried to give pilots at least 30 hours in the air before they were given wings, but they were often driven to give them less. He himself had qualified for his wings in 13 hours. In 1915 he believed that they pushed some pilots over to France after only 12 hours in the air. He had often wondered how things would have worked out if they had delayed matters by giving everyone twice as much training as was actually received; he was certain we should have had far fewer casualties. One of the qualities necessary in an instructor was certainly patience. Quite a number of our finest pilots had started so badly that they had nearly been "turned down" during the early stages of their training. He believed he was right in saying that Ball was one of these. He was nearly turned down at the Central Flying School, but he was so keen that he was given another chance, and he turned out to be one of the finest fighting pilots the world had ever seen. It was hard to imagine a better system of training the military pilot than that at present adopted. The Avro was a perfect machine, the engine was good enough for the purpose, and with them it was possible to get into any position in the air with perfect safety. As to commercial flying, if aerial transport were to boom in two years or so, we should not have sufficient trained pilots, and the problem would arise as to how these pilots were to be created. Their training would be different from that of a military pilot. The latter had to do every form of stunt, had to do without instruments, etc. The commercial pilot did not want the particular qualities demanded from a fighting pilot. Colonel Searle, when he was managing director of A.T. and T., had evolved an interesting theory. He had suggested dual control on every machine, and that an apprentice pilot with no training except as a mechanic should be put up beside the pilot and fly with him for six months or a year. This apprentice would act as mechanic to the pilot, and the pilot during his flights would slowly get him into the way of working the controls. He was not at all sure that this was not a possible method. The commercial pilot need never stunt but would have to fly in cloud, in the dark and every sort of weather and could always use his instruments. It might be urged that that sort of training might not make a good service pilot. Well, it would not make a good fighting pilot, but he would be useful for night flying, bombing, etc. He agreed with the lecturer that flying was perfectly safe. The weak point of flying was that one could not afford to make a mistake. Eliminate mistakes and flying was the safest thing in the world.

Wing Commander BOWEN recalled his early training and his training after the war and paid a tribute to the work of Smith-Barry. He was chiefly interested in the human reactions which came into play in flying, and his own knowledge on this subject was taken almost entirely from Dr. V. Anderson's extraordinarily interesting book on "Medical and Surgical Aspects of Aviation." There were three senses used in flying, and if one analysed the present system of teaching people to fly one realised that practically only one sense was really trained, *i.e.*, the visual sense. Although the author had mentioned that pupils were taught to listen to the note in the flying wires, he rather gathered that that was the sole extent to which the auditory reaction was trained at all. The third important reaction was the tactile reaction, or sense of touch, and that came in to an extraordinary extent in stunting. It should be explained to cadets exactly how these reactions worked, and how extraordinarily important it was to keep themselves fit. The visual reaction was roughly $1/5$ th of a second, and the others were both about $14/100$ ths of a second in a normal person. If they were not kept fit they might go down to half a second. He had tried flying with his eyes shut, at a safe height, and had found it extremely easy. The more one left everything entirely to one's sub-conscious self, and trusted to tactile and auditory reactions, the simpler it was. People had to fly in clouds, and he suggested quite seriously

that they should be taught to fly to a certain extent with their eyes shut, and come to trust to their natural reactions. Continuing, Wing Commander Bowen referred to the turn indicator which was being developed and might be of interest to flying instructors, particularly to those training pilots for civil aviation. It was getting to a point now at which it was beyond the experimental stage, and it was solely a question of getting the thing to stand up to ordinary service. It would be interesting to know whether it was considered by expert flying instructors that it would be of any utility in their work. With regard to civilian pilots, it seemed to him that one of the greatest troubles in the past, and to a certain extent now, was in trying to impress upon pilots the fact that if they had instruments to help them they should get 100 per cent. out of their instruments. For flying big, heavy machines we were bound to come more and more to instruments, and he suggested that when training pilots the full importance of instruments should be impressed upon them.

Mr. A. V. ROE said serious consideration should be given to the question of starting from the ground, that is, he thought the landings should be taught first, not last, the pupil to be taken for "hops" or short flights near the ground for a start, allowing the pupil more or less to handle the machine, the flights to be gradually increased in length and turns indulged in until the pupil was thoroughly used to landing, then the usual existing course could be taken. He thought after a preliminary course of this nature the total flying hours required in order to learn to fly would be reduced. He drew attention to the fact that the world's record for quickly learning to fly was made by Pemberton Billing, who obtained his certificate in about an hour before breakfast one morning, without any previous flying experience. Some object to this method, for they say the pupil would be rather apt to seize the control stick, which would be dangerous near the ground, but it was a simple matter to fix springs on the controls, so that the instructor could master the pupil. He noticed in the paper that one man had taken 20 hours to learn to land, but if one started from the ground then one got some idea of how far the ground should be from the seat when landing, and it seemed much easier to land the machine if a number of preliminary hops had been made. As to controlling the aeroplane, the position of the pupil behind the instructor was very good. He personally liked that idea because he thought it gave the pupil more confidence, whilst the instructor could not so easily see the nervousness of the pupil if he was inclined that way (laughter). Then there was the question of the communication between the instructor and pupil. Indicators could be used, but a good telephone wanted a lot of beating, especially as now there are telephones in which the voice is amplified. Referring to economy, Mr. Roe said his firm had been experimenting with an air-cooled engine, which was considerably more economical than the rotary type, and of course had advantages over the water-cooled engine.

Group Captain E. F. BRIGGS said the scheme in progress at present for the development of flying instruction was very much better than the old scheme, and the short time taken for the average pupil to become really proficient vindicated its adoption. In the old days at Eastchurch they never had much instruction, although he did not think a great number of undercarriages or machines were broken up. One instructional aeroplane had lasted for something like $2\frac{1}{4}$ years. He had been an advocate of using instruments for starting the instruction of pupils. In the olden days one had to rely entirely on feel, and he had had the advantage of being in close touch with the designers of the first air speed indicator of the type now in use, when first brought out, and of the application of Wright's principle of the "piece of string," with which one could accomplish in some measure what the gyro turn indicator now allowed one to do in clouds. Again, on the question of levels, he believed that the first one used was an old Admiralty boiler gauge glass, slightly curved, with a cork at each end. Personally, he preferred the piece of string to the cross level. Pilots should be instructed in the

use of such instruments as are fitted in aircraft. He was rather sorry they had heard nothing about seaplane instruction. He did not quite know what was the best method to adopt in this connection. Some people maintained that they ought to have small flying boats for training, and others the two-float type. He understood that at present most pupils who went in for sea work first qualified on land planes, then on the two-float types, then on the big boats with dual control. Dual control as in the big boats would probably be the best method for instructing commercial pilots in large land machines, although he would rather like to venture an opinion which was that all pilots, whether for naval, military or civil flying, should go through a common initial training, and those who went in for commercial work should transfer to the reserve. By this system prospective commercial pilots would have had full initial training and would obtain their final instruction on dual control with the big air-line pilots in the heavy machines. He however imagined the insurance people might create a stir if an accident occurred, and if they knew that one of the pilots under instruction was in command at the time and possibly doing his first landing with twelve passengers and valuable goods on board. With regard to the relative positions of the pupil and the instructor, a two-float dual control seaplane was just being completed, but in this type of aircraft one had far more controls to manipulate than in the "Avro," as there was the "flap gear," tail adjusting gear, radiator shutters, etc., and other adjustments to make. In this particular seaplane the pupil is situated in the seat he would normally occupy were he flying by himself, and he asked the author's opinion, from an instructional point of view, as to whether this position should be occupied by the pupil or the instructor. As to air-cooled engines, unfortunately, the Air Ministry had such a stock of "Mono Gnoms" that there was very little likelihood of getting air-cooled engines adopted for training for some time, although he believed that the amount of money saved in the long run would more than outweigh the cost of introducing air-cooled engines into the training service. In the East, particularly, air-cooled engines would be economical, because he believed the sand played havoc with the mono Gnome. The engines in the East did roughly 20 to 30 hours running, and a good radial air-cooled engine might perhaps run 150 or 200 hours without overhaul.

The CHAIRMAN asked whether that would be a fixed engine.

Group Captain BRIGGS said yes. Continuing, he said it seemed a pity that pupils had to be instructed on the effects of the gyroscopic action of the rotary engine. He presumed that these rotaries would be replaced before long by high power fixed radial engines. When this transpired it would appear advisable to put the pupil through his initial training on an engine, or a type of engine, which would be in use in other service aircraft. With regard to Mr. Pemberton Billing learning in one hour, it happened that there was a pretty considerable bet at stake and this probably accounted for the short time taken to obtain the "ticket."

Captain W. H. SAYERS said he first went up in 1911 as a passenger with a well-known pilot, on his first flight after he had taken his ticket, and had had an excellent opportunity of watching him learn to fly (laughter). Fortunately, he learned very quickly. He had another experience, when he had to run the Avro Flying School at Brooklands. Not being a qualified pilot, he was theoretically not allowed to fly. When a pupil stopped his engine at the end of the ground he had adopted the practice of getting into the seat, getting the pilot to start his engine, and then himself taxi-ing the machine back. This was an excellent deterrent to this annoying habit. He had found, however, that it was much simpler and much less dangerous to fly it back at a height of somewhere about 4ft. off the ground, with the engine throttled well down, until one day, when crossing the corner of a sewage farm, something hit the machine and he found himself over the sewage farm. He was forced to climb, make a very shaky turn round the sheds and land. The latter required five attempts before success was

attained and the effect on his and the pupil's nerves put an end to flying for that day.

Since then he had been subjected to instruction of the dual control type in various degrees of completeness, and his last experience had been at the hands of a "Gosport" type instructor. This was not so much instruction as a demonstration of the things an Avro ought not to do, but did do, and so was perhaps not a fair sample.

But it was the most terrifying experience he had yet had in the air—much worse than his first circuit. He had been learning to fly for the last ten years, but officially did not know how to yet. The old method of teaching a pupil on a relatively low-power machine, which could not get very far off the ground, and turning him loose, was capable of producing extremely good results, with a good machine and a good, sensible pupil. In 1912 they had turned out something like six pupils on one machine, and without breaking anything more serious than one wire.

The pupil of to-day knew more about flying before going into the air than anyone knew in the old days.

The Chairman had referred to Park's dive and said Park did not know what happened. He (Captain Sayers) was associated with him at the time it happened and he did know very definitely what he did.

The CHAIRMAN: It was a spin?

Captain SAYERS replied that it was, but Park knew definitely that he got out of it by putting his stick forward and centralising the rudder. With regard to civil pilots, everybody would agree that they ought not to stunt. At the same time, it was undoubtedly the fact that they ought to know how to stunt, and ought to know that they knew. There was always the possibility of getting into an awkward position from which one could only recover by something in the nature of a stunt.

Dr. A. P. THURSTON said it was a well accepted fact among psychological specialists that most men might be divided into two main types, *i.e.*, visualists and auditives. The latter type did things more or less by happy inspiration, without really knowing how and relied instinctively on the sub-conscious brain, whereas the visualist belonged to the hard thinking scientific type, who must be convinced definitely as to every step in the process before allowing the sub-conscious brain to take control. The northern races had a much larger proportion of the visualist class, and the southern races a larger proportion of the auditive, but whether a man belonged to one class or the other, the sub-conscious brain composed the great mass of the brain and was much more ancient and more highly developed than the conscious brain. It seemed to him, therefore, to be an excellent thing to instruct a pupil most carefully what to do when various difficulties arose and why those difficulties arose, and then to take him into the air and show him how to get out of those difficulties. It used to be the practice during the war to take a pupil into the air, put the machine into a spin during his first flight, tell the pupil through a telephone that he was in a spin and that it was quite easy to get out. What he had to do was to centralise the rudder and push the joystick forward. Then he was told he would be put into a spin again and would have to get out himself. That gave him confidence which he never forgot. Engine failure had not been brought into prominence that evening and was in the speaker's opinion the second great danger. Engines failed just at the psychological moment, when they should not, and they could fail in the air in only three ways—spark, pressure or throttle, except, of course, for mechanical breakage. If the instructor caused the engine to fail unexpectedly in the air in various ways and the pupil had it thoroughly ingrained in him that he should switch off and switch on to test the spark, then try the pressure and finally the throttle, it would pull him out of a nasty corner many a time. Before that wonderful invention

of Mr. Mayer engine failure due to loss of air pressure was very common, and if the engine stopped, after first testing the switch, he would turn automatically at once to the air pressure to see that sufficient pressure was recovered to supply the petrol. Another point which should be impressed upon a pupil, until it became automatic, was that when coming down the pressure of the air increased but the pressure of the air in the tank did not. It was therefore necessary to keep pumping or else he would not have the engine when he wanted it. The drilling in of these little things seemed to give confidence which could not be obtained in any other way. The development of finesse in flying could more or less be left to the pupil himself. As to landing, he had always found it extraordinarily difficult to make a full three-point landing, whereas if they were allowed to come down a little faster, and not make altogether a good three-point landing, they would make a much more certain and much more competent landing. Our machines should be designed so that it would be possible to make a good three-point landing without having to pull up the nose of the machine 10 to 15 degrees, and so obstruct the view of the ground and set the pilot's judgment out by altering the inclination of all the lines of the machine relatively to the ground. That was one point in regard to which the science of construction could be considerably improved at the present moment. Pilots could then land practically at the same inclination as that in which the eye had been trained when flying at height.

He was glad Captain Sayers had pointed out that the honour of discovering how to get out of a spin is due to Lieutenant Park, R.N. He remembered the incident quite well on Salisbury Plain in 1912 and found the information of use long afterwards when he got into an involuntary spin.

Flight-Lieutenant BALFOUR said he believed the author was wrong in regard to the method of instruction which taught the pupil to fly level, then turn at an angle of about 45 degrees first and then vertically afterwards. The best method was to teach, first, to fly level, then vertical, and then come back to the 45 degrees. Flying at 45 degrees was far harder than flying vertically owing to the elevator fulfilling a dual function when machine is at 45 degrees. With regard to moral, the whole thing was one of the instructor possessing moral which he could impart to his pupil. Referring to Mr. Roe's point as to training a pupil from the ground. This would give a pupil too much to think of at one lesson. By teaching in the air first, it would be found that it was as much as a pupil could do to learn to control a machine in the air in three or four hours. Do not mix him up by teaching of flying level and landing in the same lesson; they should be kept as separate and distinct.

Flight-Lieutenant FORBES-BENTLEY said that in the old days, 1912 and 1913, one always knew where there was an aerodrome, because there were generally lorries or carts going towards them carrying broken machines. During the war he was very close to an aerodrome where a number of pupils were being taught on Henry Farman's, and there also there were numerous crashes. He backed up Captain Sayers in saying that Lieutenant Park did know how he got out of his famous dive. Speaking of the instruction at Cranwell, he had had the rather unique experience of having been attached there for fourteen months, in a part of the aerodrome from which he had a good view all round, and during the whole of that period he had not seen a crashed machine, which compared very favourably with past records, and showed the value of the training advocated by the lecturer.

Squadron-Leader PORTAL, replying to the discussion, first dealt with the Chairman's remark that the method of coming out of a spin was discovered by a French pilot in 1916. When he (the speaker) was an observer, about the middle of 1915, his pilot got into a perfectly good spin in a Morane, about 300ft. from the ground, and they had got out of it before reaching the ground. He agreed with Wing-Commander Bowen as to the importance of the three senses used in flying, and that the tactile and auditory senses were very, very important, but

maintained that to teach a pilot by means of those two would be practically impossible. They must teach a pilot by visual methods and he would soon, from his own experience, get the help which all pilots derived from tactile and auditory senses. As to the use of turn indicators, he was inclined—as the duties at his station were only concerned with what might be called the simple, straightforward A B C of flying on the Avro, which formed the basis of other sorts of flying—to the view that their introduction would lead to complications in elementary instruction. Both Mr. Roe and Captain Sayers had advocated training from the ground. There were, however, two very serious objections to that method, in practice. In the first place, there might be 18, 20 or 25 pupils learning at the same time, and if they had 25 pupils rushing about on the ground at all angles and speeds, and probably with their heads inside the cockpit wondering what was happening to the throttle, there would be more crashes than occurred in a modern ballroom, with far more serious results. An even more serious objection was that in any wind that method could not be pursued. A pupil could run along into the wind all right, but if there were a wind of about 20 miles an hour, he would stand a good chance of being blown head over heels when he turned to come back. That would be all the more likely when there were a lot of pupils turning quickly, and trying to avoid running into each other. In the air, however, one could reach in a 50-miles-an-hour wind just as well as in a dead calm. Group Captain Briggs had referred to instruments. He (the speaker) very strongly maintained that it was folly to teach a man from the start to depend in any sense on his instruments. Probably he did not lay sufficient emphasis on it in the paper, but he was serious about the earwig. If an earwig did happen to get into the pitot tube, and woke up, it might mean that a pilot would be killed if he was depending on his instruments. That was an extreme case, but that was the principle in the minds of instructors. No instructor ever thought of mentioning the word “instrument” to a pupil in these days. They had their value, but it was not in teaching elementary flying. He was in agreement with Group Captain Briggs that the pupil should be in the same seat throughout instruction as that from which he would fly an aeroplane afterwards. Dealing with Mr. Thurston’s remarks, the author said he would rather fly with a visualist than an auditor. Although he recognised the great ability of Flight-Lieutenant Balfour, both in the air and elsewhere, he did not agree that the vertical turn should be taught first. Flight-Lieutenant Balfour was in a minority of one, with an opposition of about 15 or 20 instructors who were very nearly as good as himself, and the speaker took it on their authority and practical experience that the proper place for the 45 degrees turn was immediately after the level flying, the reason being that it was not such an unexpected position to get into as the 90 degrees turn. That was the real reason it was taught after level flying. As to Flight-Lieutenant Balfour’s remarks on moral, he (the author) did not lay sufficient emphasis upon it in what he had said in the paper. He realised that what Smith-Barry did for flying was even more from the point of view of moral than from pure technical efficiency.

The CHAIRMAN said he was glad to discover that we British could claim to have found out how to come out of a spin. He never knew it before, and it was a pity that the simple cure for the spin had not been generally made known earlier. The spin was one of his worries in 1914 and 1915; none of our instructors were prepared to go into a spin and try these methods of coming out at that time. Although he agreed with the lecturer that it was sound to train pilots without instruments, he did not agree with Wing-Commander Briggs that it was possible to fly in cloud without instruments with safety. In bad clouds even the best of pilots had been thrown out of control. The younger de Havilland was nearly killed when flying in really bumpy storm clouds over mountains. The turn indicator was the most valuable instrument we had at the present time. We had outlived the idea of training “from the ground” as Mr. Roe termed it. He was convinced that the dual control method was much the best way of teaching normal

men to fly, both from the economical and safety points of view. He had thrown down a bone of contention in the shape of Colonel Searle's idea and several people had risen to criticise it. At heart he personally was convinced that all pupils had to become *airmen* first, and the best way to teach them was a thorough training on an Avro machine, followed by training on specialised types. The trouble he saw in front of us was that if aerial transport really began to move we should not be able to get a sufficient number of properly trained pilots, and we might have to find a means of producing them quickly without the advantage of the Avro training, which, of course, was too expensive for an air transport firm to adopt. In conclusion, the Chairman expressed the thanks of the meeting to the lecturer for his most interesting paper.

The thanks of the meeting were accorded with acclamation and the proceedings terminated.



REVIEW.

Research in Industry. By A. P. M. Fleming and J. G. Pearce. (Sir Isaac Pitman and Son.) Price 10s. 6d.

With the many ills brought by the war there were a few gains; one was the increasing recognition of the importance of scientific research in the national life. Readers of Professor McDougall's well-known book, "National Welfare and National Decay," will recollect the attention which that psychologist gives to the idea that nations survive only in virtue of their power to produce leaders whose mental outlook shall be fully equal to the growing complexity of the problems which changing life presents. Much of that complexity is directly due to man's gradual conquest of the forces of nature; much to the greater consciousness of the conditions of their lives due to the spread of education among all classes. The idea is a compelling one and, if accepted, renders it of first importance to facilitate in every way the path of the research worker in the hope that, by this means among others, our race will always be "on the top" of our industrial problems as the latter arise.

The present book is therefore doubly welcome. It discusses the nature of research, the best material means for its efficient performance, the nature of the research worker in person and the international character of research. Present-day governments in the leading world states are more or less alive to the situation; possible alternative governments in such states are a more uncertain factor. But it will be noted with pleasure by many readers that the authors are able to place on record a manifesto by the American Federation of Labour in favour of research which opens with the very striking recognition that "whereas scientific research and the technical application of the results of research form a fundamental basis upon which the development of our industries, manufacturing, agriculture, mining, and others must rest; and whereas the increasing productivity of industry resulting from scientific research is a most potent factor in the ever-increasing struggle of the workers to raise their standard of living, and the importance of this factor must steadily increase since there is a limit beyond which the average standard of living of the whole population cannot progress by the usual methods of readjustment, which limit can be raised only by research and the utilisation of the results of research in industry. . . ." The breadth of view here expressed by those who would not be expected by their education to be so much in advance of the ideas prevalent but a few decades ago is most welcome. A wide realisation of its wisdom will be of immense benefit.

The authors correct not a few misapprehensions in their analysis of the nature of research. It frequently happens that attempts are made to lay out plans for research work—whether "pioneer" or "applied," according to the authors' division—to a definite programme and to prescribe at once anything of the nature of the dreaded "overlapping" of research. The authors point out, on pages 47 and 134, that research work in pure science cannot be systematised, that each worker should be allowed to proceed according to his vision, that there must be freedom of action for the worker to select his subject and develop it, and further that overlapping, "far from being a crime," is often a necessity. The authors rightly stress the immense importance of facilities being afforded for the publication of results; they point out that the extra emoluments obtained in industrial research, as compared, for instance, with University fellowships or lectureships, will not compensate the worker with the true research spirit if publication is denied him.

A very interesting feature of the book is the series of illustrations of research laboratories in every part of the world; they are seen to be ingeniously and ably

planned in their internal arrangements. But they are usually, alas! found to be designed externally with but little regard to the elements of beauty. Surely the time must be near when it will be realised that the beauty which always accompanies a design aptly fitted to its purpose may fittingly (indeed profitably) be associated with beauty of external environment.

That the authors have first hand knowledge of the subject on which they write could easily be established on internal evidence alone. What research worker will not recognise the truth of the advice that: "It is a good plan to arrange a certain amount of work as a relief to the research work, and this may even be routine work. The performance of a set task at specified intervals well within a worker's capacity will restore self-esteem which is apt to dwindle if a long period of non-success or failure of inspiration occurs in performing a major research."

We are grateful to the authors for their labours and we hope that those responsible for research work in aeronautics will take an early opportunity to study this book.



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All communications should be addressed to the Editor.

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JUNE, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council meeting held on Tuesday, May 16th:—

Student.—W. K. Mackenzie.

Associate Members.—H. V. Bullbrook, E. C. Gaccon, F. W. Gaccon, P. Hoggins, P. E. Williams.

SCOTTISH BRANCH: *Associate Member.*—James Hamilton.

Wilbur Wright Lecture.

The Annual Wilbur Wright Lecture will be delivered at 5.30 p.m., on Thursday, June 15th, in the Theatre of the Royal Society of Arts, John Street, Adelphi, when Lieut.-Colonel A. Ogilvie, C.B.E., F.R.Aë.S., will read a paper on "Some Aspects of Aeronautical Research."

Research.

The Council are again considering the question of the continued reduction in expenditure on research by the Air Ministry. The views of the Council on this matter, as laid before the Secretary of State for Air at an interview on January 17th last, will be found in a previous number of the Journal (Vol. XXVI., at page 43).

Committees.

The following is the full list of Committees appointed for the year ending April, 1923:—

Candidates' Committee.—Prof. L. Bairstow, Prof. B. Melvill Jones, Wing Commander T. R. Cave-Browne-Cave, Squadron Leader R. M. Hill, Prof. C. F. Jenkin, Mr. W. O. Manning, Dr. N. A. V. Piercy, Dr. A. J. Sutton Pippard.

Finance Committee.—Mr. Griffith Brewer, Lieut.-Col. A. Ogilvie, Mr. A. E. Turner (Hon. Treas.), Mr. F. P. Walsh.

Publications and Library Committee.—Prof. L. Bairstow, Major F. M. Green, Squadron Leader R. M. Hill, Major A. R. Low, Mr. J. D. North, Lieut.-Col. H. W. S. Outram, Dr. A. J. Sutton Pippard, Mr. J. L. Pritchard (Editor)* and Major R. V. Southwell.

The Chairman (Lieut.-Colonel M. O'Gorman) and Vice-Chairman (Air-Commodore H. R. M. Brooke-Popham) are *ex-officio* members of all the Society's committees.

Representatives.

The following members have been nominated by the Council to represent the Society on other bodies for the year ending April, 1923 :—

Air League of the British Empire.—Lieut.-Col. M. O'Gorman, Rear-Admiral M. F. Sueter, and the Secretary.

Joint Standing Committee with the Society of British Aircraft Constructors.—Prof. L. Bairstow, Wing Commander T. R. Cave-Browne-Cave, Lieut.-Colonel A. Ogilvie, Major-General Sir R. M. Ruck.

Conjoint Board of Scientific Societies.—Lieut.-Colonel M. O'Gorman.

Aeronautical Research Committee.—Lieut.-Colonel A. Ogilvie.

Advisory Committee on Aeronautical Education.—Prof. C. F. Jenkin.

British Engineering Standards Association. Aircraft Committee.—Lieut.-Colonel M. O'Gorman. *Nomenclature Sub-Committee.*—Prof. L. Bairstow, Mr. J. D. North, Lieut.-Col. M. O'Gorman, Dr. A. J. Sutton Pippard, Major R. V. Southwell, and the Secretary.

Civil Aviation Advisory Board.—Lieut.-Col. M. O'Gorman.

International Air Congress, 1923.—Mr. Griffith Brewer, Lieut.-Colonel A. Ogilvie, Lieut.-Colonel M. O'Gorman, Lieut.-Colonel W. Lockwood Marsh (Technical Secretary).

Students' Section.

The date of the students' visit to the National Physical Laboratory has been changed from Saturday, June 3rd, to Saturday, June 10th. Students desiring to attend are reminded that they should meet at 9.15 a.m. for special tickets at the Booking Office, Waterloo Station (L.S.W.R.).

Binding Cases for the Journal.

The arrangements made for the binding of complete sets of the Journal in blue cloth cases with gilt lettering at a charge of 4s. 6d. per volume, including the supply of the case, are still in force. Members who desire to take advantage of this arrangement should forward their sets direct to the Lewes Press, Ltd.; High Street, Lewes, at the same time sending a remittance for 4s. 6d. to the Secretary at the Society's offices. A note stating the name and address of the sender should be included in the parcel to the binders. The complete volume will be returned direct to members postage paid.

W. LOCKWOOD MARSH, *Secretary.*



CORRECTION.

In Major Barlow's paper, page 153, paragraph 3, the law of densities should read :—

$$\rho_H/\rho_{II} = P_H/P_{II}.$$

PROCEEDINGS.

NINTH MEETING, 57th SESSION.

A meeting of the Society was held at the rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, March 2nd, 1922, the Chairman, Lieut.-Colonel M. O'Gorman, in the chair.

The CHAIRMAN, introducing Mr. William D. Douglas, A.R.C.Sc.I., A.F.R.Ae.S., and in calling upon him to read his paper on "Testing Aircraft to Destruction," said he had done much to develop methods of testing aircraft, both to destruction and also for their eventual survival.

TESTING AIRCRAFT TO DESTRUCTION.

WM. D. DOUGLAS, A.R.C.Sc.I., A.F.R.AE.S.

SYNOPSIS.

1. Introductory.

Necessity for strength tests to supplement calculations and to check the assumptions on which the calculations are based. Historical outline. Examples of certain types of defect which are revealed by strength test.

2. Description of Present Methods.

Assumed aerodynamic conditions. Approximations reproduced by test loading. Methods of support during test. Measurements, testing routine and technique.

The usual tests are described :—Flight test, C.P. forward ; Flight test, C.P. back ; Nose dive test ; Tests of auxiliary and controlling surfaces ; Ailerons, elevators and rudder ; Tailplane and fins ; Fuselage, down load, side load, torsion ; Undercarriage, discussion of stresses which may arise during landing, pointing out presence of frictional horizontal force causing rotational acceleration of the wheels ; Static tests of undercarriages, dropping tests ; General description of rib tests.

3. Conclusion.

Description of shot bags and general principles of load application with a view to efficiency and safety.

Introductory.

In many branches of engineering fatal results may follow simple errors, but nowhere is this so evidently true as in aeronautics. The aeroplane designer, however well equipped with technical knowledge and armed with the recorded experience of the aircraft world, cannot afford to neglect any opportunity of detecting the occasional mistakes which he is liable to make, and of rectifying the same before they reveal themselves in the air.

Efficient inspection, checking of calculations, etc., serve to eliminate the majority of the dangerous defects in design and material, but there are certain forms of weakness which are not evident under simple inspection or which may owe their origin to faulty assumptions and which may therefore escape detection if the assumptions are common to the designer and the checker

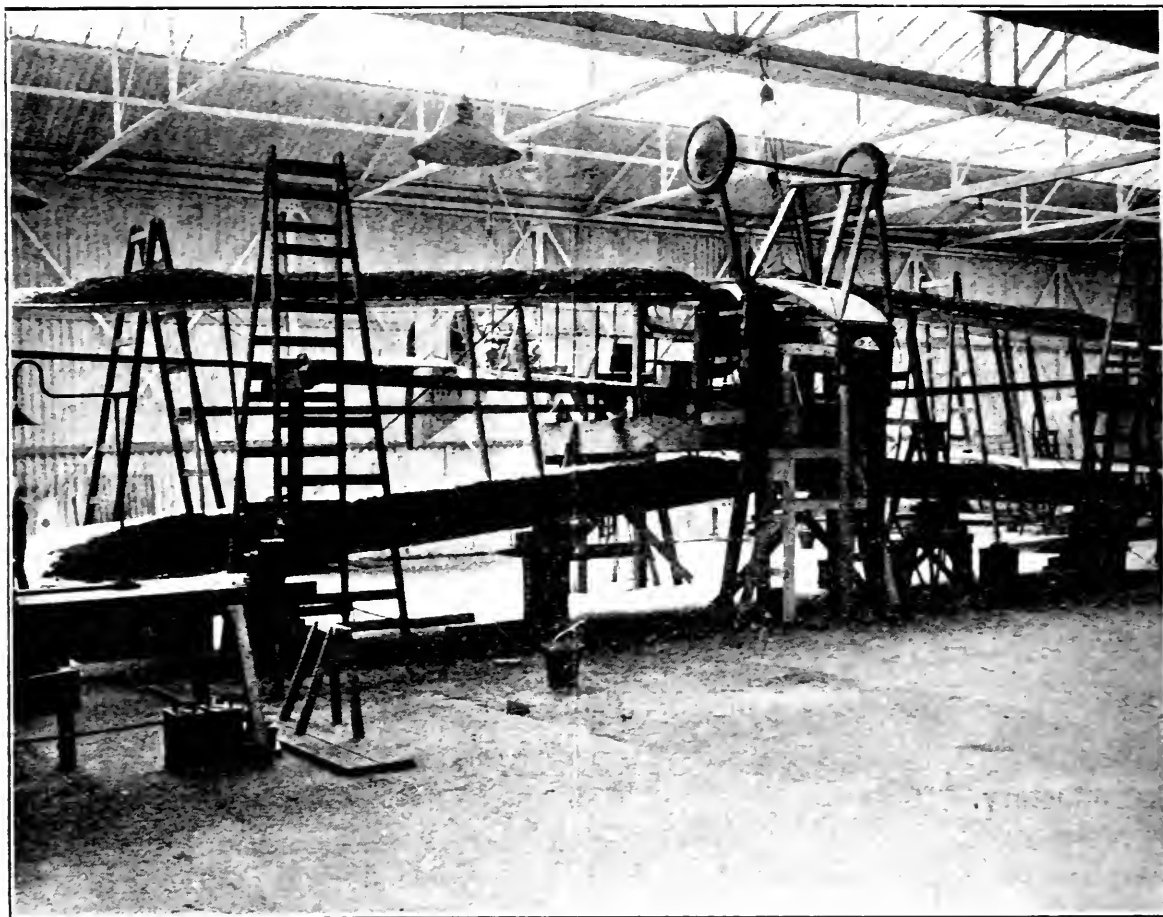


FIG. 3.—*Sand as a loading material.*

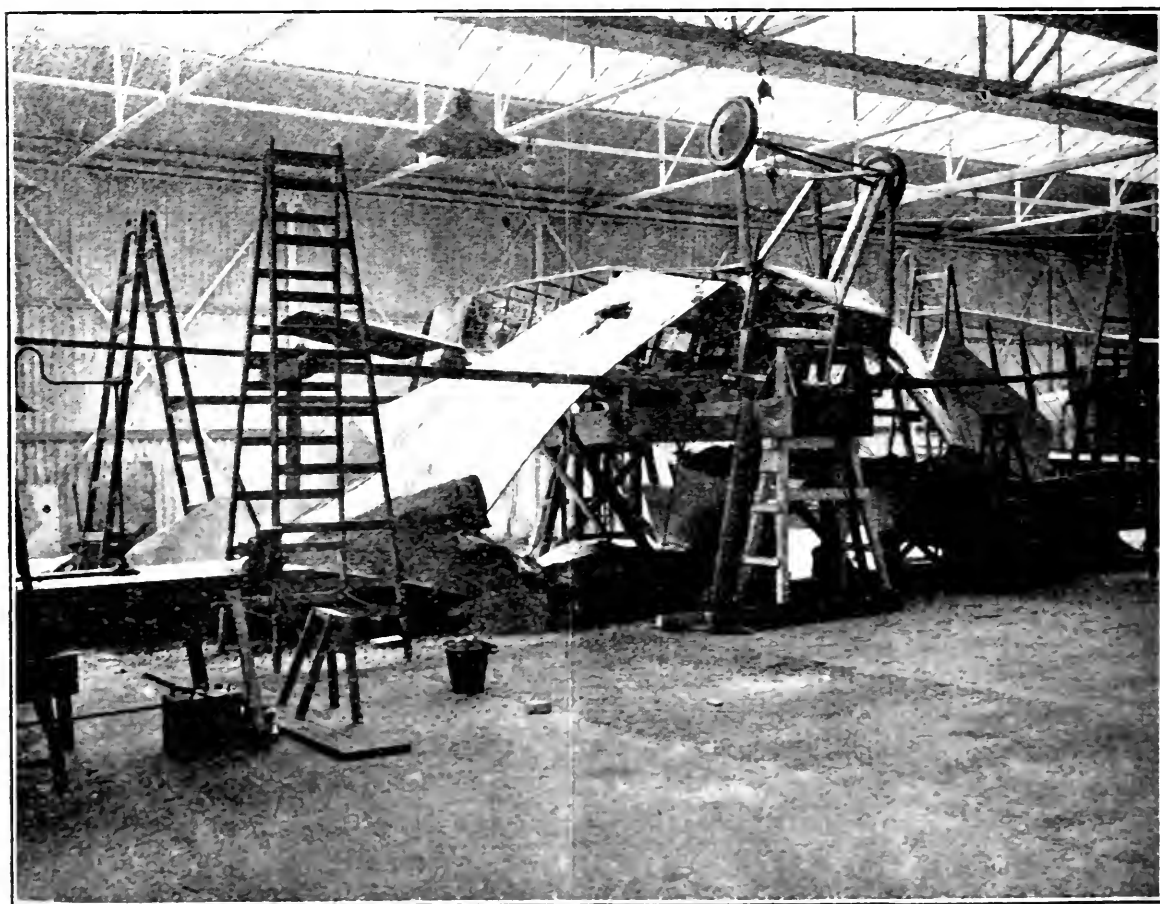


FIG. 4.—*Result of allowing complete collapse.*

Even in the early days of aircraft construction, designs were occasionally submitted to simple forms of strength test. Fig. 1,* which appeared in "The Aero" of August 3, 1910, illustrates one of the first recorded tests of this nature, where M. Levavasseur, the designer of the famous Antoinette monoplanes, is conducting a static loading test on a port plane. To prove his confidence in the correctness of his calculations he is photographed while seated under the loaded structure. This heroic method of proof is not recommended, although certainly it would tend to eliminate bad designers. Fig. 2* shows the plane after collapse. It is of interest to notice that the load consists of wood planks, which could not be expected to produce the correct bending in the spars as the pile of planks would in itself resist bending, and the greater part of their weight would be transferred to the points of support of the plane.

In succeeding years, a gradual improvement in methods of test may be traced. Various materials were used for loading purposes, including bricks (either loose or packed in boxes), gravel and sand.

Fig. 3 illustrates the type of main plane test at Farnborough, 1914 to 1916. Loose sand was mainly used, and no precautions were taken to prevent the complete collapse (Fig. 4) of the structure, with the result that it was difficult with certainty to determine the location of primary failure.

The use of sand, which is an entirely unsuitable loading material, whether loose or in bags, was soon discontinued, and for the last six years loading has been done by means of suitably designed, and accurately weighed, shot bags or by lever systems. In any case where it is necessary to use a granular loading material on small surfaces, loose shot is employed, as it possesses the following advantages over sand.

- (a) "Arching" effect is less evident.
- (b) Weight is not dependent on moisture content.
- (c) Maximum loading gradient is two and one-half times greater than dry sand.
- (d) Bulk is much less.

The obsolete term "sand test" is of course misleading, and its occasional use as recently as 1918 gave rise to many misconceptions.

Typical Failures during Test.

Before outlining the methods at present employed for testing aeroplane structures it will be of interest to examine some typical failures which are obtained from time to time. The following have been selected for their illustrative value, and since some of the actual parts photographed failed at loads considerably in excess of those for which they were designed, they should not be taken individually to indicate weakness of any particular type of machine or errors on the part of any particular designer.

For permission to use the information and accompanying illustrations in this Paper, I am indebted to the Air Ministry and to the Superintendent of the Royal Aircraft Establishment, Farnborough.

Fig. 5 shows a lateral failure of the spars where the front and rear spars have buckled forwards in the inner bay in the plane of the chord.

If the plane had been covered with new fabric during the test, this type of failure would have been prevented. If the spars are weak in the plane of the chord, a satisfactory test could be made by having slack or weathered fabric in place. Since it is difficult to obtain a particular plane with fabric of a suitable degree of slackness, tests are usually made with the fabric entirely removed.

* Not printed.—EDITOR.

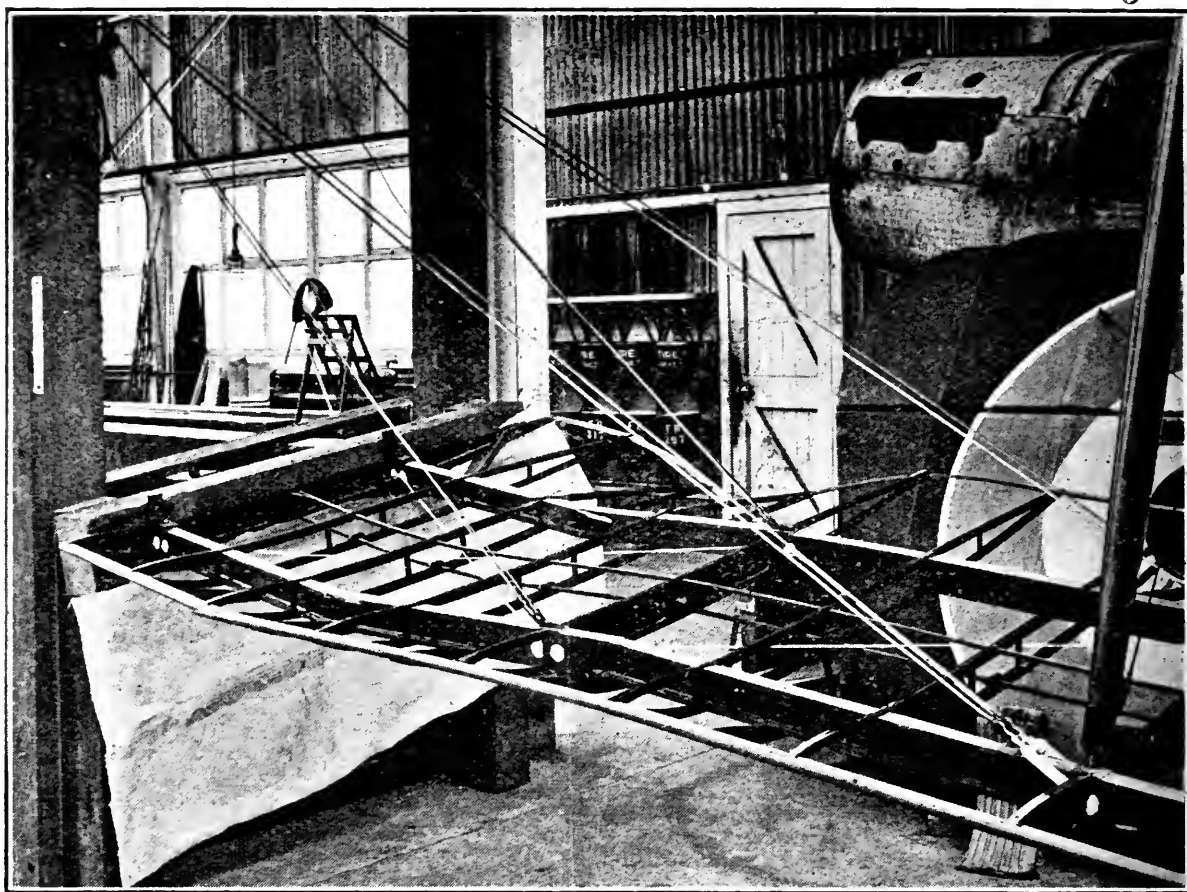


FIG. 5.—*Lateral failure of spars.*

Fig. 6 shows a very common case where the yielding of timber under a steel fitting and in front of a bolt has allowed such distortion that the forces brought into play cause failure of one of the parts at a load less than that for which the fitting has been designed.

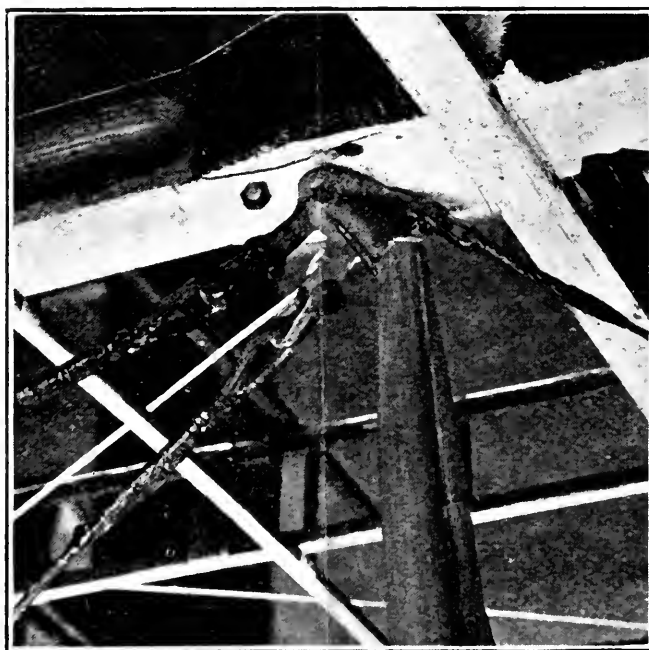


FIG. 6.—*Movement of bolt in timber.*

In this particular case it will be seen that one of the ordinary bolts after shearing through the spar for about half an inch has failed. The pull of the

lift cables has tilted the fitting and the end of the strut has fractured above the socket.

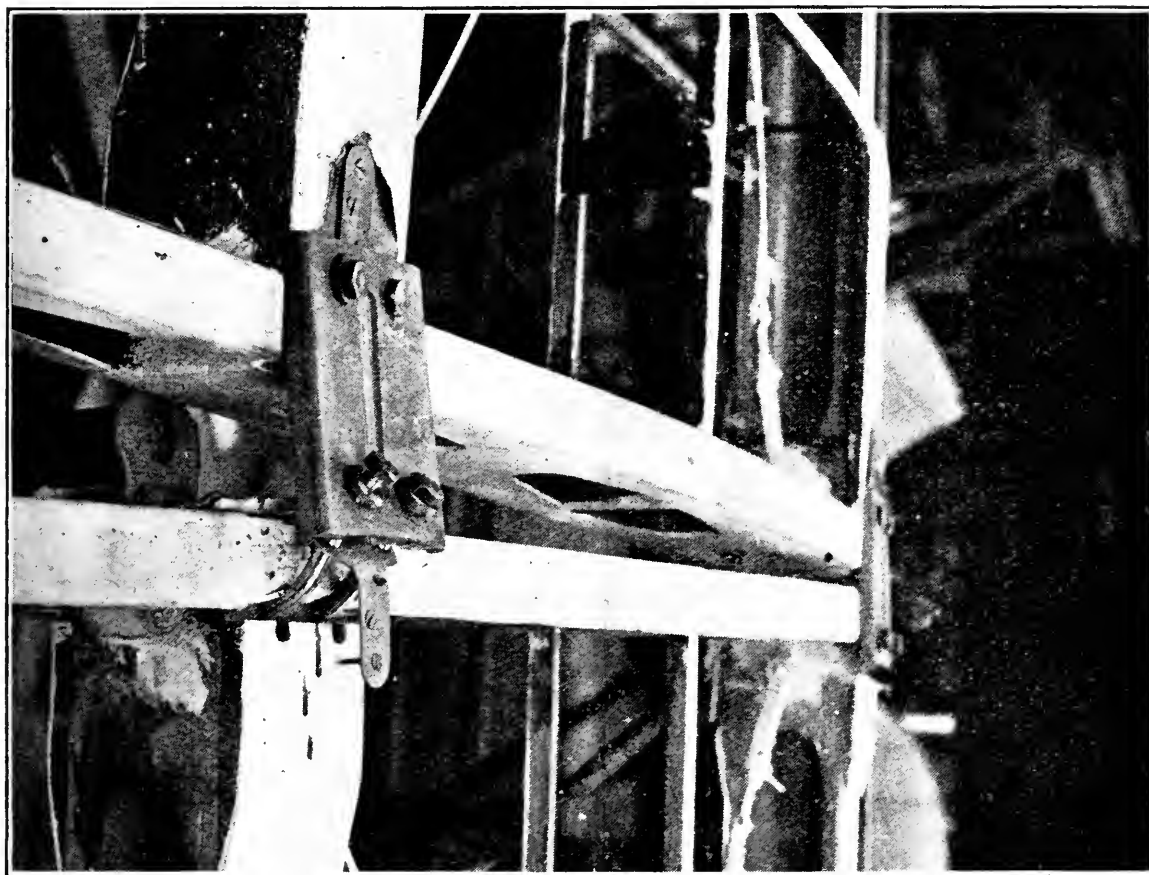


FIG. 7.—*Bolt failure at centre section.*

Fig. 7 shows a somewhat similar type of failure where the bolts attaching a top main plane to the centre section have sheared through the wood of the spar and finally failed in the threaded portion.

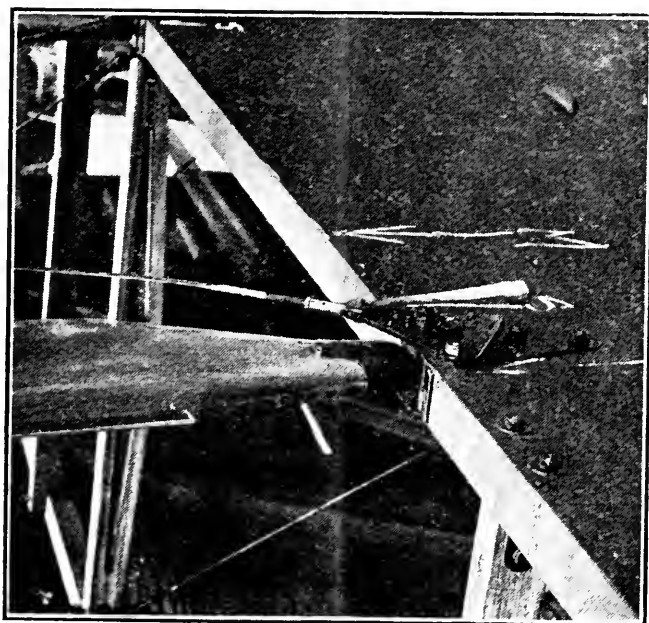


FIG. 8.—*Excessive bearing pressure under fitting.*

Observation of the preliminary phases of the distortion of bolts in timber is possible with X-rays, and the use of a comparatively simple set would be of advantage in many instances.

Fig. 8 shows an example of a simple bracket (under a centre section strut) which allowed too great a bearing pressure on the timber of the fuselage longitudinal on which it was mounted. The crushing of the timber might have resulted in local weakness of the longitudinal, but having been revealed by the test, it was of course easily prevented in other machines of the type.

In ailerons, elevators and similar control members it is sometimes convenient to mount control levers or their bracing attachments at the side of, or offset from, one of the ribs. The calculation of the stresses due to such mounting is complex, and in such cases designers usually trust to their general sense of proportion guided by previous experience. Fig. 9 illustrates a case where failure has occurred

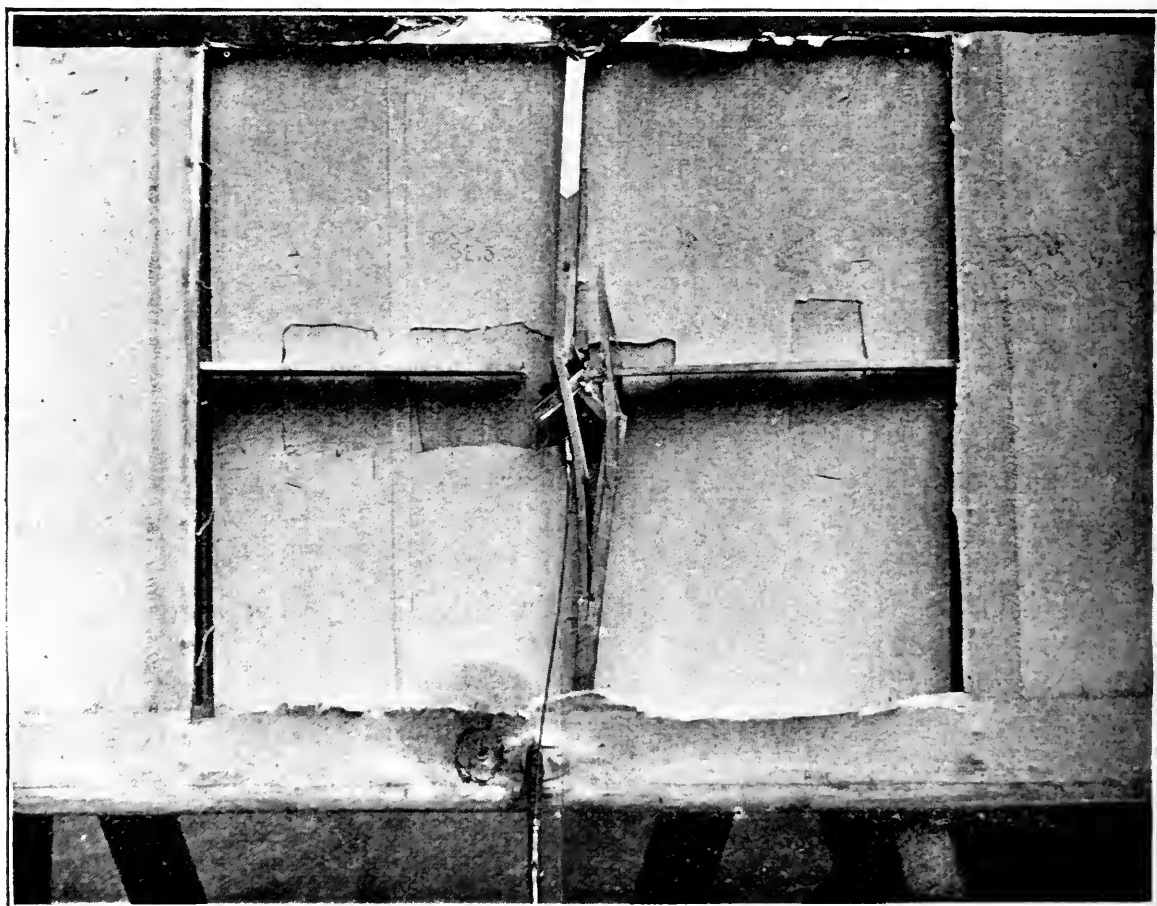


FIG. 9.—*Offset bracing attachment.*

in such an offset attachment for the bracing wire of a control lever. The same remarks apply to control pulleys, often mounted on cantilever fittings, which may deflect or even tear away long before the ultimate strength of the remaining parts of the control has been reached. Fig. 10 and Fig. 11 may serve as examples.

Down load or side load on a fuselage usually produces a failure of the tension bracing or of the longitudinals. In the latter case either one or both of the longitudinals which are in compression fail as continuous struts. Fig. 12 shows a case of this nature.

It will be seen that the bottom longitudinals have buckled outwards in one bay and inwards in the adjacent bay. This fuselage was tested without fabric covering, since the bracing effect of the latter is a variable and somewhat doubtful factor.

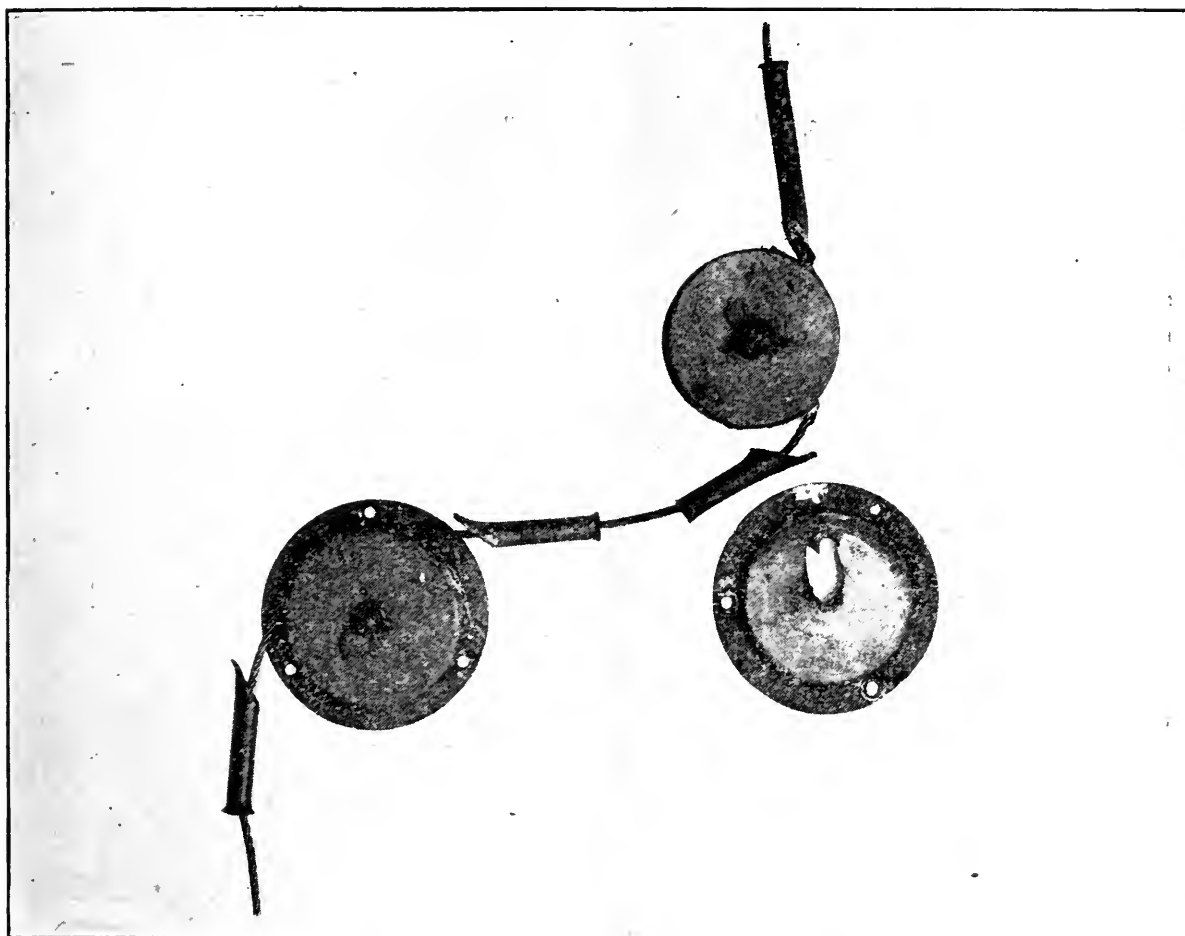


FIG. 10.—*Failure of pulley fitting.*

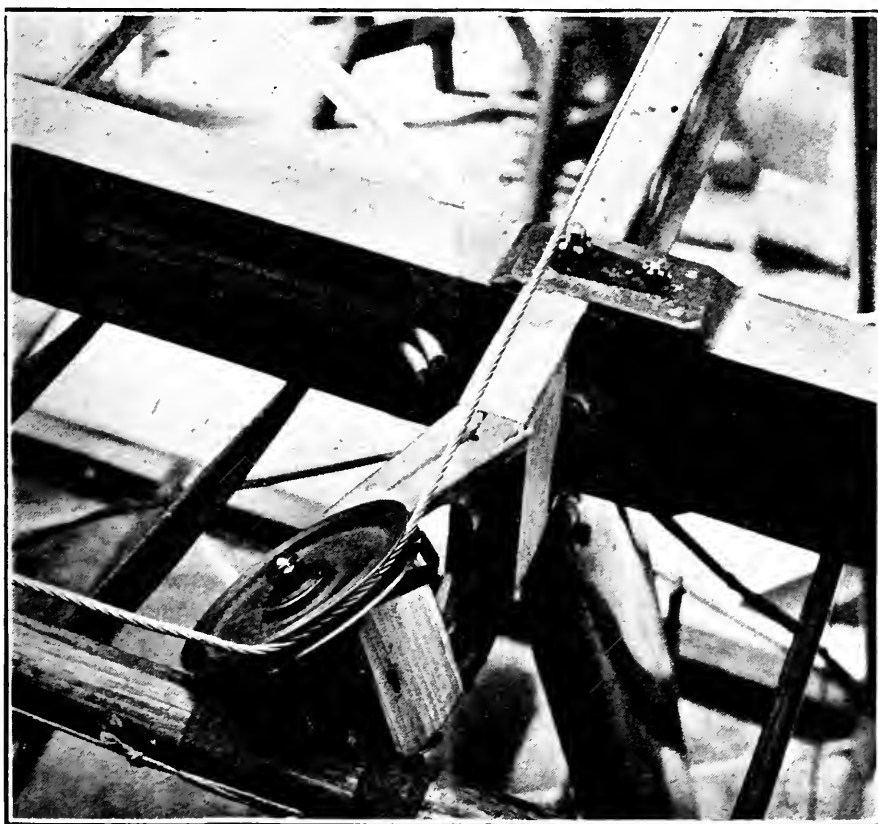


FIG. 11.—*Failure of pulley mounting.*

Occasionally the fuselage joint fittings distort or fracture. An example of the latter is shown in Fig. 13, where the pull of the bracing wire on the left-hand side of the illustration has caused fracture of the light alloy casting which acts as a socket for the fuselage strut. This illustration also shows the stretch of the bracing due to the terminal loop closing, the ferrule slipping along the wire.

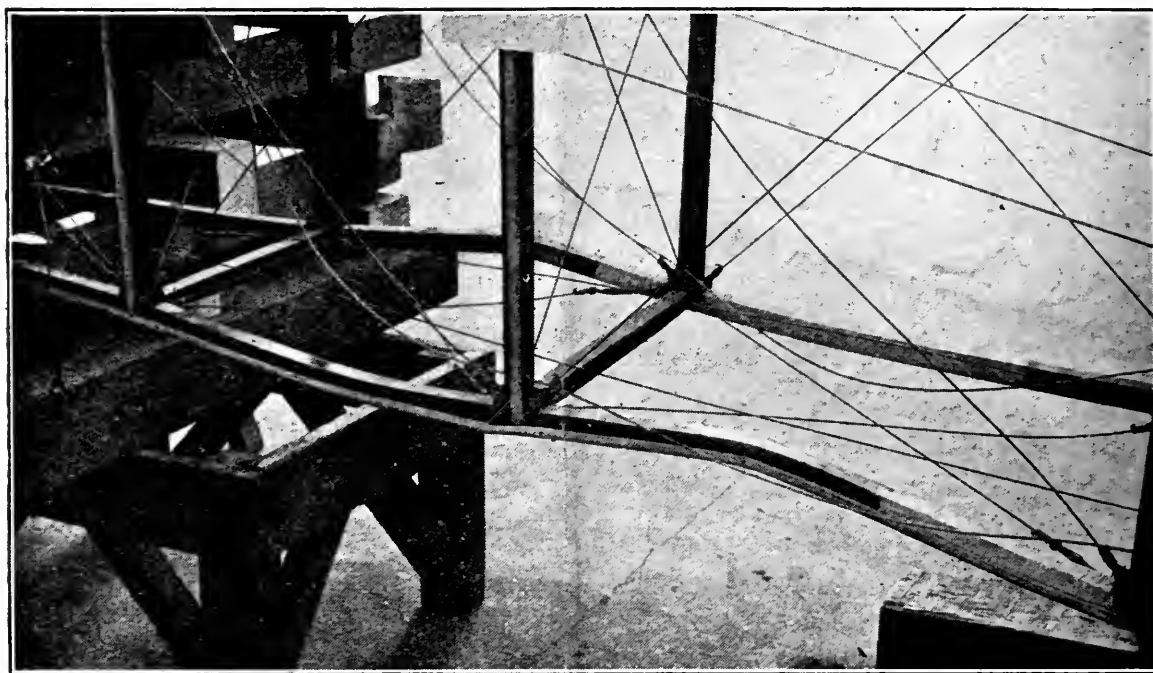


FIG. 12.—*Failure of longitudinals.*

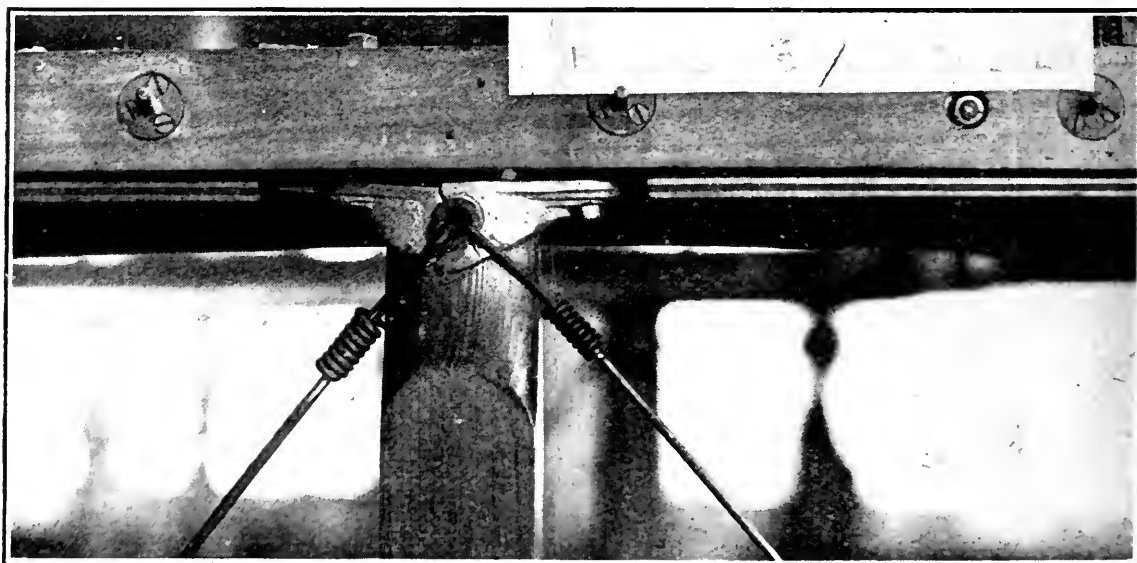


FIG. 13.—*Failure of fuselage fitting.*

Fig. 14 illustrates the "V" strut of an undercarriage which has buckled at A and subsequently distorted on the opposite side of the axle.

A somewhat similar example is shown in Fig. 15, where the front strut of a "V" undercarriage has buckled inwards and forwards. The fairing and the rubber shock absorber were removed after test for photographic purposes.

Present Methods of Testing Structures.

The following description gives only a brief outline of the main tests which are frequently applied to the structure of conventional types of medium and small size machines. The limits of the present Paper do not permit any reference to special tests which are called for as occasion demands nor to the extension of testing methods to large or unusual types of aeroplanes. Tests of spars, fittings, materials, etc., are also omitted.

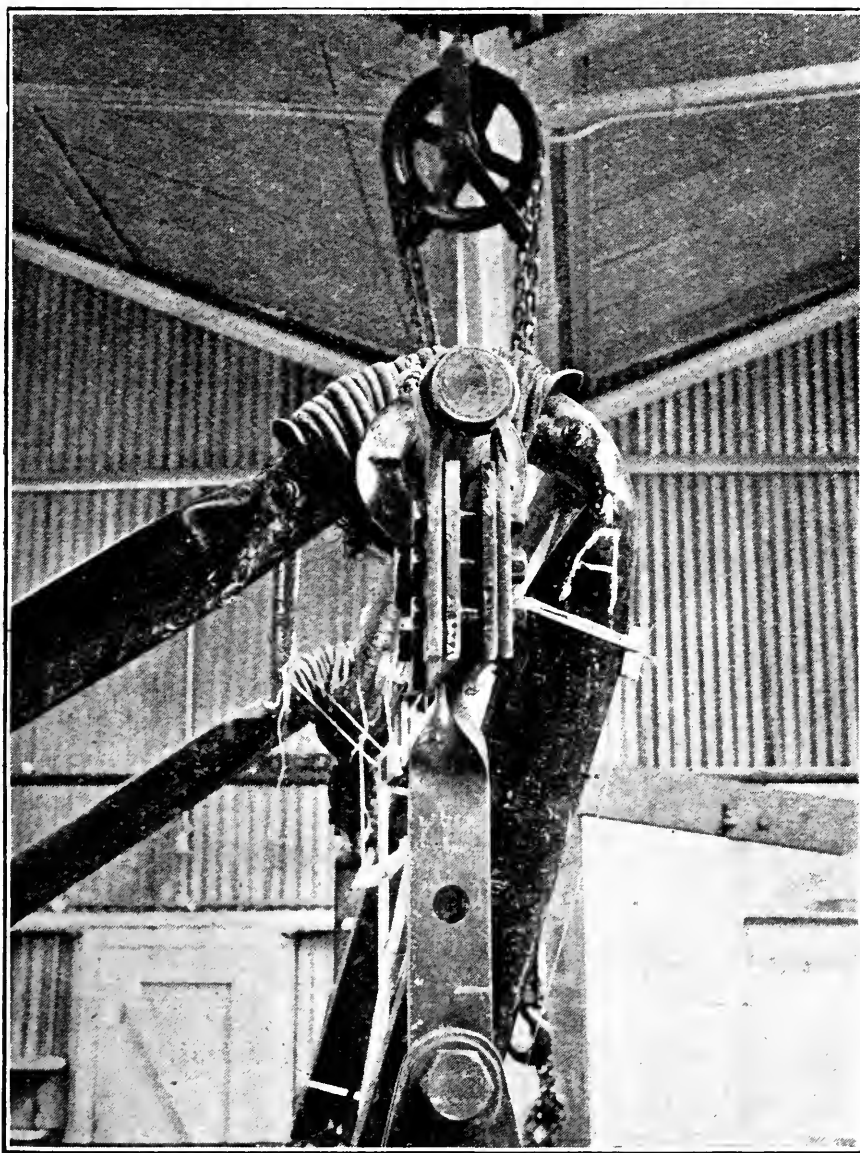


FIG. 14.—*Buckled undercarriage strut.*

In the formulation of any test the following procedure is usually adopted :—

- (a) The particular conditions to be represented are ascertained.
- (b) The airloading under these conditions is obtained or assumptions founded on the best aerodynamical data available are made.
- (c) In many cases it is necessary to assume some modification of the above airloading to suit the limitations of the test loading process.
- (d) Arrangements are made for the gravitational or other acceleration forces, which balance the air force, to be represented by controlled reactions supplemented, if necessary, by other applied forces.

Consider a typical case. For any given speed the maximum lift force which can act on the main plane of a machine will occur when the planes are at their stalling incidence. This condition might occur when pulling out of a dive, and the speed at the instant might, therefore, have a high value.

Complete information as to the distribution of lift and drag forces and of pitching moments is not available for all wing sections, but where the section in question bears a general resemblance to the standard sections for which data exist, no great error is likely to result from intelligent interpolation.

The distribution of the air forces having been decided, or assumed, it will be found that the resultants of the lift and drag forces on the various cross-sections of the planes do not all act in exactly the same direction. Since gravita-

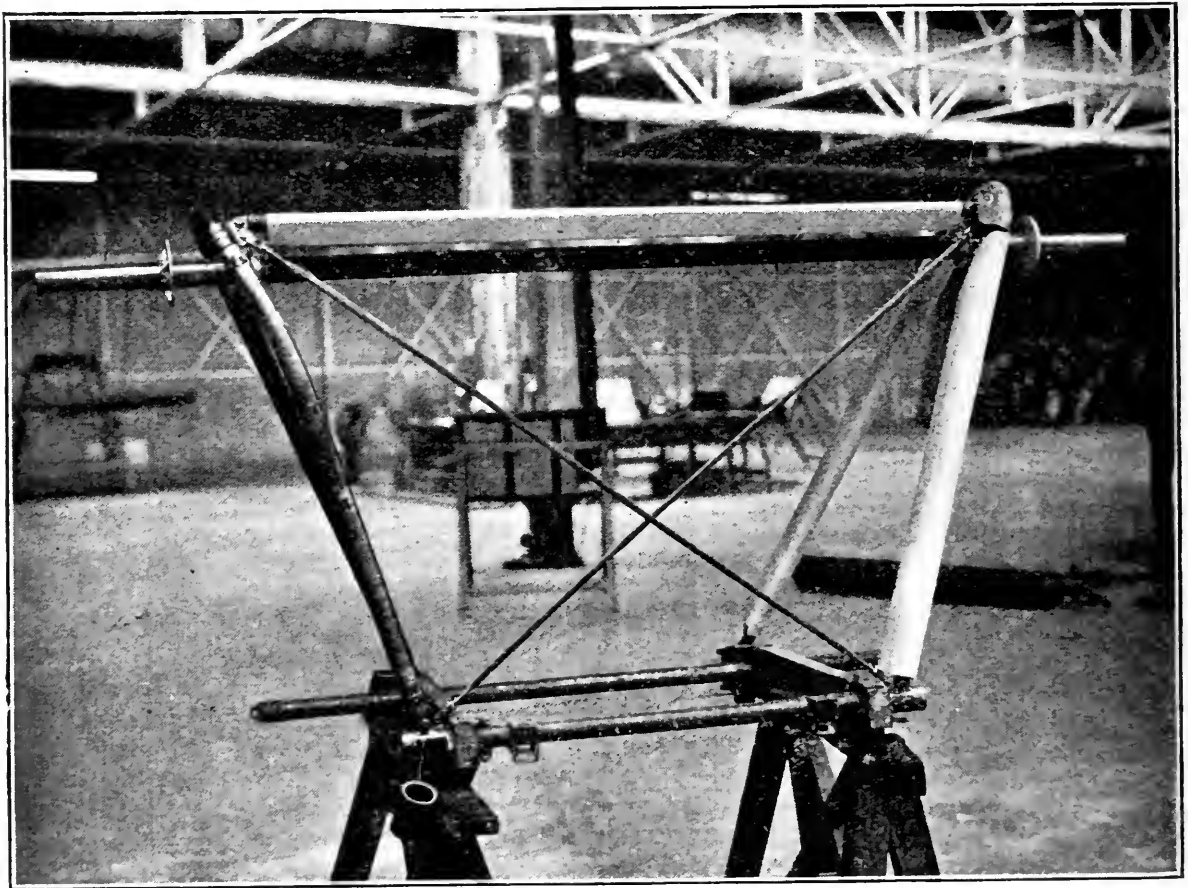


FIG. 15.—Undercarriage after test.

tional force is to be utilised to represent the resultant air force, it will only be possible to reproduce a distribution of forces in which the lift and drag components at the various cross-sections bear a fixed ratio and have therefore a uniform direction for their resultants. This direction must, of course, coincide with the direction of the resultant air force on the whole main plane system. These approximations and assumptions are familiar to all, as they form the usual basis of design calculations.

Except where there are definite reasons against so doing, it is usual to assume that the drag component is everywhere $1/7$ th of the lift, that the centre of pressure coefficient is the same for every cross-section of the plane and that the grading of the loading along the span is uniform to within a definite distance from the tip.

The attitude of the machine during test will necessarily be fixed, since the resultant air force on the planes is to be represented by gravity. The diagram in

Fig. 16 illustrates the case where the stalling angle of the plane is 16° . Fig. 17 illustrates the same machine inverted and mounted for test, the attitude of the machine being arranged so that the relative direction of the resultant air force is vertical. The latter may, therefore, be represented by gravitational force.

For strength calculation purposes, the attachments of the main plane structure to the fuselage are usually treated as fixed relatively. This approximate assumption is unavoidable on account of the extreme complication of the structural calculations when the deflection and distortion of the various members in the central part of the fuselage are taken into account. Fortunately, this limitation

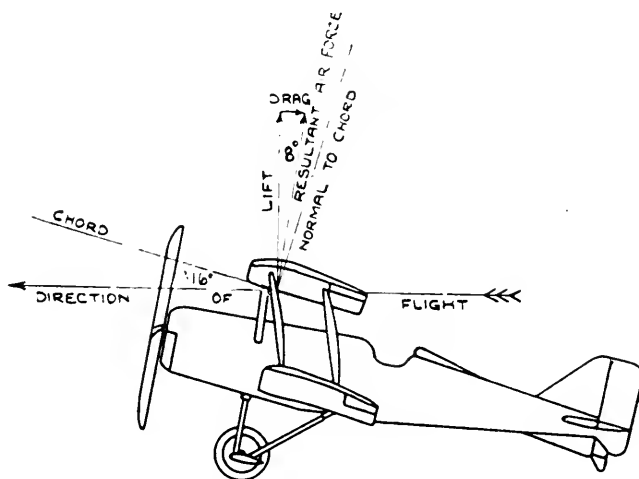


FIG. 16. CONVENTIONAL LIFT & DRAG FORCES ON AEROPLANE AT STALLING INCIDENCE.

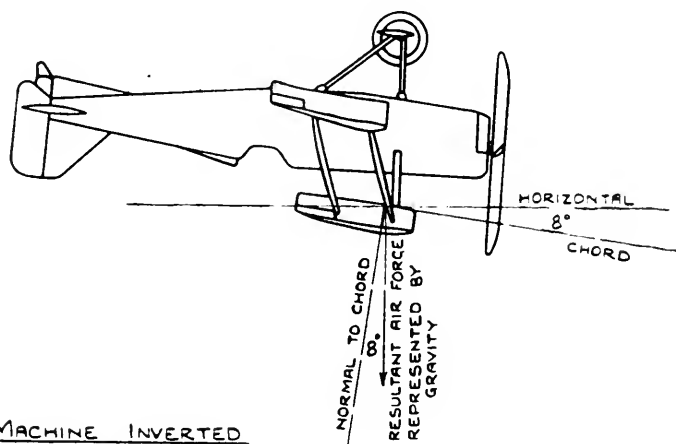


FIG. 17. MACHINE INVERTED IN ATTITUDE FOR TEST.

is less evident in testing, and it is possible to arrange for the main plane attachments to deflect relatively under load in a manner similar to that which might be expected to take place in the air. This may be effected by arranging that the reactions of the fuselage supports will represent the mean acceleration forces which act on the fuselage and its attachments.

Approximation is again necessary, since it is evidently impracticable to support each member of the fuselage and its contents separately. A suitable compromise may be made by selecting four to six points of support corresponding with the main weights such as engine unit, tanks, crew, undercarriage, etc. (see Fig. 18). When the machine has been erected for test, supports may be placed at the points selected as above, using a simple system of levers to ensure that the

reactions have the desired relative values. Each support may be arranged so that its reaction passes through the centre of gravity of the particular mass concerned. The ratio of the reaction forces will not be made identical with the ratio of the isolated masses, but will be modified so that the resultant reaction will pass through the centre of gravity of the whole machine.

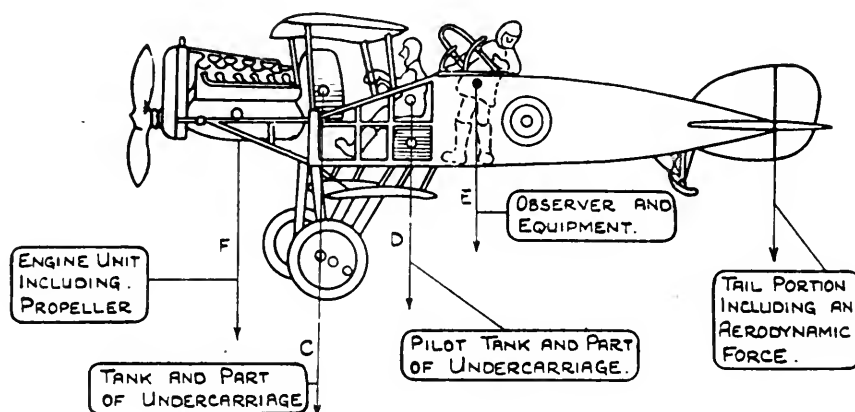


FIG. 18. DISPOSITION OF CHIEF MASSES IN TYPICAL MILITARY FUSELAGE.

SUITABLE PROPORTIONS OF THE MASS OF THE FUSELAGE STRUCTURE
MAY BE INCLUDED WITH THE VARIOUS ITEMS INDICATED ABOVE.

For equilibrium, a further force will be necessary; this may be supplied by securing the tailplane at, say, the hinges of the elevators. The reaction, thus automatically brought into play when the planes are loaded, will represent roughly the aerodynamic load on the tailplane under the flight conditions which have been assumed.

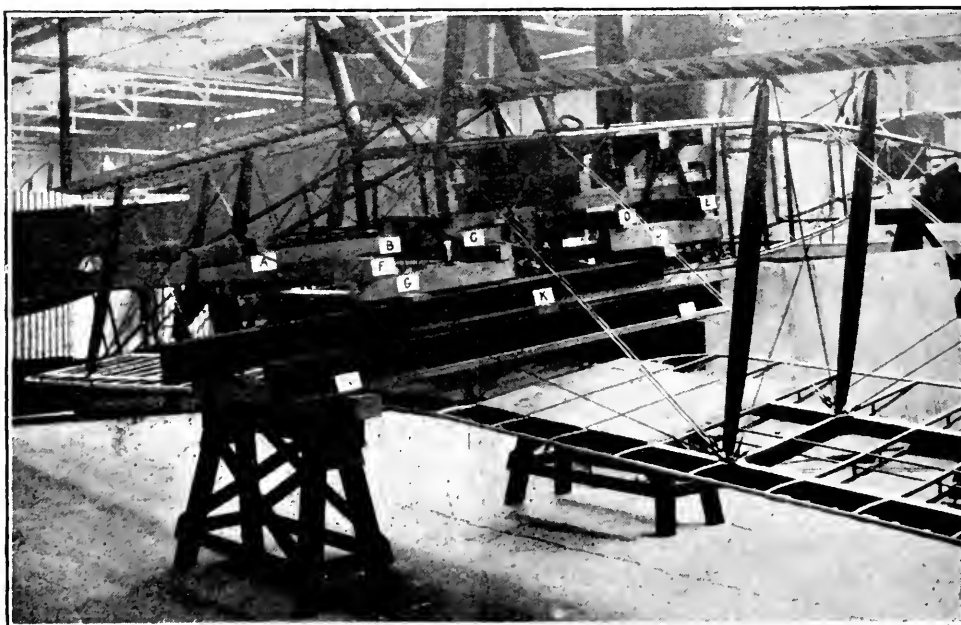


FIG. 19.—*Arrangement of supports for main plane test.*

Fig. 19 shows a Bristol machine mounted in course of preparation for test. Supports at "A" and "B" represent the engine unit, and the reactions act on the engine mounting. The lever "AB" rests on a cross bar "F" placed under the position of the centre of gravity of the engine unit. A support at "C" fitted to the tank mounting represents the acceleration force on the main tank and part

of the undercarriage. The reaction from the support "D" is distributed on the seat bearers to represent the pilot, the tank over which he sits, and remaining portions of the undercarriage. Support at "E" represents the observer and his military or other equipment. By means of wooden beams and levers pivoted at "G" and "H" and a short steel lever pivoted at "K," the reactions on the supporting points are distributed as desired. The point "K" and a corresponding point for the other side of the fuselage are arranged in the plane containing the centre of gravity of the aeroplane.

To prevent the machine rocking, the tail is supported and secured to a heavy trestle.

In some special cases the mounting of the fuselage is a matter of considerable difficulty, since adequate provision must be made to ensure safety during various possible types of collapse. Fig. 20 illustrates such a special case, showing a Supermarine A.D. Boat erected for test.

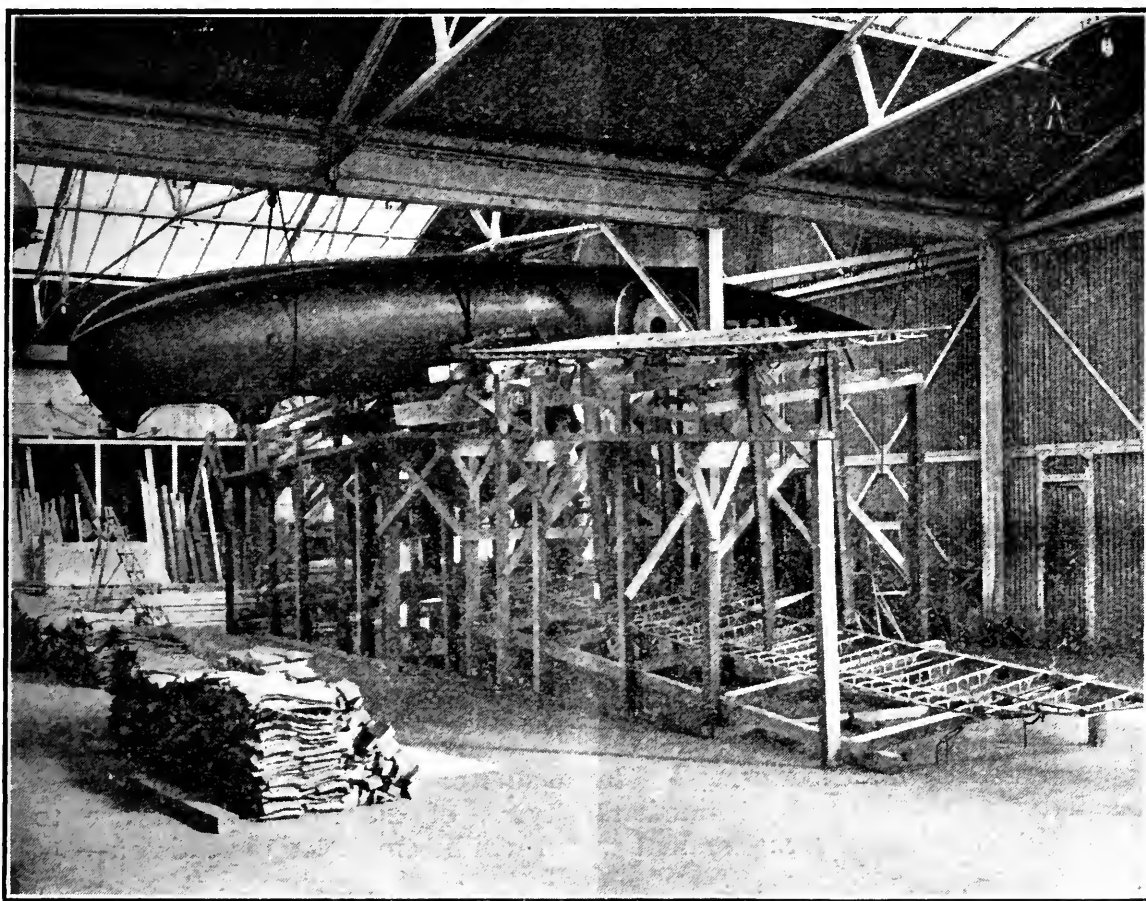


FIG. 20.—"A.D." boat arranged for test.

Details.

During test the engine will be removed, and it is then necessary to insert some temporary stiffening members to represent in the fuselage the bracing effect of the crankcase. An iron plate drilled and bolted to the engine bearers is usually sufficient.

Load is applied to the spars of the main planes. The fabric is removed and boards are laid across the front and rear spars. As has already been explained, the presence of new fabric will generally prevent failure of the spars in a direction parallel to the chord. Although such failure might possibly be facilitated by the slacker fabric that occasionally results from weathering in service, the absence of fabric is advantageous since it permits of easy inspection of the

spars, the internal bracing and the fittings during the progress of a test. This is specially important in wood structures, as incipient failure is frequently evident a considerable time before collapse. Where the planes are covered with three-ply or metal sheet which forms an integral part of the rib structure, it is necessary to make the tests with the covering in place.

The position of the centre of pressure of the assumed air loading is marked on the boards with chalk. The divisions along the span are also indicated and loading is conducted by placing shot bags in these divisions symmetrically over the centre of pressure line. In the case where the fabric has not been removed, it is necessary to distribute the load along the chord. In such cases it is usual to apply the load in two rows approximately over the spars, the relative values being arranged so that the resultant centre of load coincides with the assumed position for the centre of pressure.



FIG. 21.—“ Y ” level and staff.

Measurements.

Although in many cases the primary object of the test is to determine the ultimate or collapsing load, an endeavour is always made to obtain from the test the maximum amount of information by means of observation and measurement of distortions. Having determined the types of distortion which are to be measured, the method of measurement which will be employed depends on—

- (i) The accuracy required;
- (ii) Local conditions which may preclude the use of particular methods; and
- (iii) Liability to disturbance during test.

In tests of the main plane structure, information can usually be obtained bearing on—

- (a) The deformation of the framework.
- (b) The distribution of loads in members.
- (c) The deformation, etc., of the spars.
- (d) Bow of struts.

The deformation of the framework (a) may be obtained from measurements which give—

- (i) The rise or fall of strut points on the top spars.

For this purpose, readings are taken by means of a "Y" level on a graduated staff, the latter being held in a vertical position by an assistant at successive points along the top spars. This apparatus is illustrated in Fig. 21.

(ii) Change of stagger.

This may be measured at the trailing edge of the planes by suspending plumb lines of fine copper wire. The use of a fixed horizontal scale enables fore and aft motion to be measured with reference to the floor. These measurements are made on the top and bottom planes at the strut points. To prevent swinging, the plumb lines are damped by suspension in oil. The arrangement for this measurement is shown in Fig. 22.

(iii) Movement of fittings.



FIG. 22.—Measurement of lateral movement.

Where displacement of fittings is anticipated, arrangements can be made to observe and measure such displacements when they occur.

(b) *Distribution of loads in the members.*—This may be determined by the use of strain gauges on the wires and cables. The use of tensionmeters has been extensively considered, but no satisfactory form has been discovered. They usually fail on account of—

- (i) Inaccuracy;
- (ii) Bulk or difficulty of use; and
- (iii) The method of measurement involving an alteration in the distribution of load in the structure.

Recourse has, therefore, been made to the simple method of measuring the strain in the member directly by means of a suitable extensometer and calibrating the actual wire and instrument at some previous or subsequent time. Unfortunately, no suitable extensometer seems to be commercially available. At present, the measurement of extension is being made by a simple but somewhat crude piece of apparatus which suffers from the disadvantage that it is liable to derangement during the test. A form of photographic instrument at present in the experimental stage promises greatly improved results.

(c) *Deflection of spars.*—The method described in (a, i) allows of measuring the vertical displacement of any number of points on the top spars. The points chosen are usually the strut points mentioned above, and others midway between. It is necessary before commencing a test to measure any initial non-alignment of the points of support and, where this non-alignment is excessive, to remove the error by careful re-rigging.

(d) *Bow of struts.*—The lateral deflections of the struts are usually measured at the centre of their length.

High Speed Flight.

A test of the main plane structure is often made under conditions representing those which occur during high speed flight at small angles of incidence. The attitude at which the machine is mounted for this test will, of course, differ from that already described, and, in general, the reaction at the tail support will be greater, stressing the rear of the fuselage to a considerable degree.

In other respects the method of test is similar to that described above.

Vertical Nose Dive.

One of the conditions of flight for which a machine is usually stressed by designers is that of flight at low values of lift coefficient when a large moment may act on the planes. Such conditions can be represented in a strength test, but complication of the erection, etc., renders the cost and time involved considerable, and the test is only justified in exceptional cases.

Fig. 23 shows diagrammatically the principal forces which act on a machine in a vertical nose dive at limiting velocity.

- (a) The moment on the planes; which may be replaced by positive and negative lift forces with a drag component. (The latter for convenience may be applied at the front spar.)
- (b) The aerodynamic down load on the tail.
- (c) The air drag on the fuselage and its attachments.
- (d) The weight of the fuselage and its attachments.

In test these forces may be represented in a variety of ways of which one is shown diagrammatically in Fig. 24. The machine is inverted and the acting forces detailed above are reproduced in the following way:—

(a) The forces on the spars, by a suspended distributed load, to represent the lift component on the rear spars, the distributed reaction of a lever suspension system to represent the down load component on the front spars. The latter reaction is suitably inclined towards the rear to represent also the drag component.

(b) The reaction of a vertical sling support represents the aerodynamic down load on the tail.

(c and d) The fuselage is drawn forward so that the suspensory system referred to in (a) is inclined at the desired angle. The direction and attachment are arranged so that the reaction represents the resultant of the air drag and of the weight of the fuselage and its attachments.

In order to prevent the weight of the fuselage parts from affecting the distribution of the various reactions, a suitable supporting force of constant amount is applied throughout the test.

A full description of such a test is given in Advisory Committee for Aeronautics Reports and Memoranda No. 588.

Down Load.

Occasionally a test is made under conditions representing down load on the main planes such as might be experienced during inverted flight or under certain

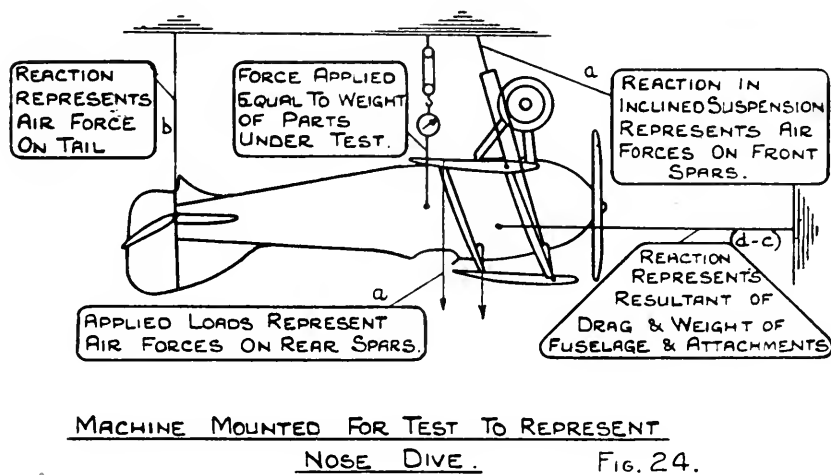
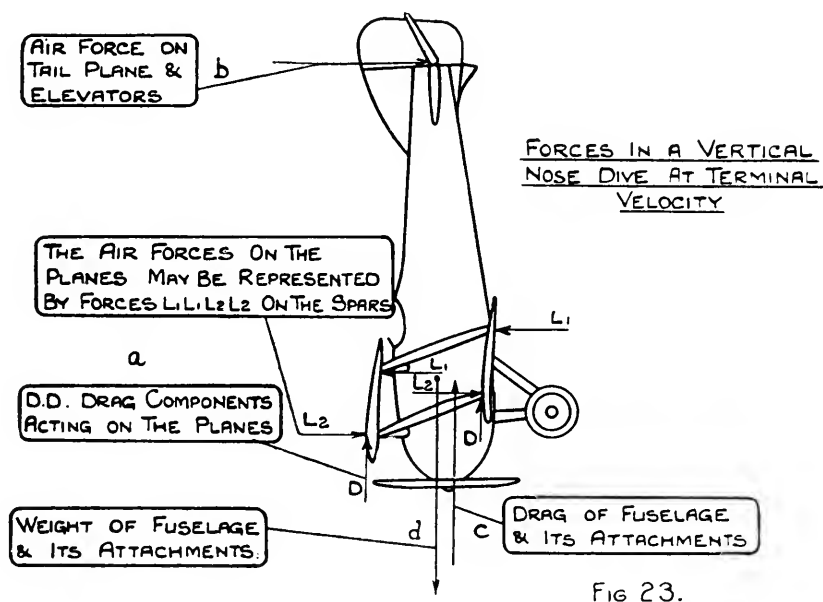
abnormal circumstances. The method of test is similar to those described above, with the exception of the necessarily changed attitude of the machine.

Auxiliary and Controlling Surfaces.

Owing to the absence of detail information as to the distribution of air pressure over ailerons, elevators, tail planes, etc., tests of these parts employ loading which is somewhat arbitrary.

Ailerons, Elevators and Rudder.

It is usual, when testing these members, to include in the tests their respective controls. The aeroplane is mounted so that the part under test, when in its



normal relative position, is horizontal. A distributed load is applied by means of shot bags so arranged that the centre of gravity of load is everywhere one-third of the distance from the leading to the trailing edge of the member. The leading edge is usually the hinge joint except at balanced portions. This procedure is, of course, based on the assumption that the loading is roughly triangular. The distribution along the span is uniform except near the ends where it is graded off arbitrarily.

The controls are so adjusted that at the commencement of test the member is tilted above the horizontal position. The application of load causes the controls to stretch so that when the failing load has been reached the member has dropped

to or below the horizontal position. The controls are secured by a cable attached to a spring balance which indicates the force which the pilot would have to exert to hold the member under the assumed condition of load.

Experience in aeroplane design shows that if ailerons, elevators or rudders of conventional type will support a load distributed as above and having an average intensity of 20 lb. per sq. ft. they are not likely to fail in service.

It is frequently noticed, especially in the case of rudders, that although at the start of the test the controls are secured at the limit of their travel so that the controlling surface is in an extreme position, stretch of the control cable and the general deflection of its attachments are sufficient to allow the loaded control surface to drop below its median or neutral position. Where the aerodynamic loading is largely a function of the angular displacement of the control surface from its neutral position (as is the case for a rudder) it is evident that at no time in flight is the member likely to experience a loading as great as that applied during the above test. It is therefore of interest in rudder tests to measure the change in angle of the rudder for various loads, the rudder bar being secured at the limit of its travel.

Tail Planes and Fins.

It is usual to test tail planes by loading their rear spars or the hinges of the elevators. This is in default of definite information as to the typical or particular distribution of air loading on the tail plane and elevators under average or worst conditions.

Where details are available as to the actual or probable distribution of air load, suitable tests are devised, each case being considered on its merits. Such tests are of special importance where the leading edge of the tail plane is more flexible than the remaining portions.

Fins are usually loaded at the same time as the rudders. The distribution is arbitrary, but the average intensity of loading is kept the same on fins and rudders and on the fins the load is distributed more or less uniformly.

Failure of fins under these conditions is not very usual, but neither is it usual in service.

Fuselage.

To some extent the fuselage is tested during the tests of the main plane structure. The central portion is stressed severely by the "stalling" and "high speed" tests. The latter imposes large strains on the rear portion also, while the former will tend to show up any abnormal weakness in the engine mounting.

A further test of the rear portion of the fuselage is frequently combined with the test of the tail plane. In this case the fuselage is usually supported at the attachment of the rear spars of the bottom main planes and held down at the engine bearers. The lateral strength of the fuselage is tested during the test of the rudder and fins; the fuselage being again supported at a section in line with the rear spars of the bottom main planes and held down near the nose. It is unusual for a fuselage to fail before the rudder.

The distortion of the framework is usually measured at certain leading points. Movement or other distortion of the fuselage fittings is carefully watched.

When monocoque fuselages are under test it is a matter of some difficulty to record the indeterminate distortions which occur in the skin while the test is in progress. These usually take the form of bulges or depressions. If, as is usually the case, the light falling on the fuselage has a preponderating direction, definite shading of the undulations will be produced. This may, if desired, be accentuated by suitable placing of the fuselage and control of the light. During the test any

undulation may be recorded by marking the contour of the high light with white chalk and the contour of the shadow with black (or coloured) chalk. If necessary, successive contours can be added as the distortion increases and each line may be numbered or marked for identification. Subsequent to the test, the fuselage may be photographed (or drawn) and the white and dark contours will accentuate the effect of the shading or, if the removal of stress has allowed the distortion to subside, the chalk lines in themselves will give a sufficiently good effect of relief to register the form of the distortion.

The Albatross three-ply fuselage distorted by down load on the tail is shown in Fig. 25 and will illustrate the above remarks.

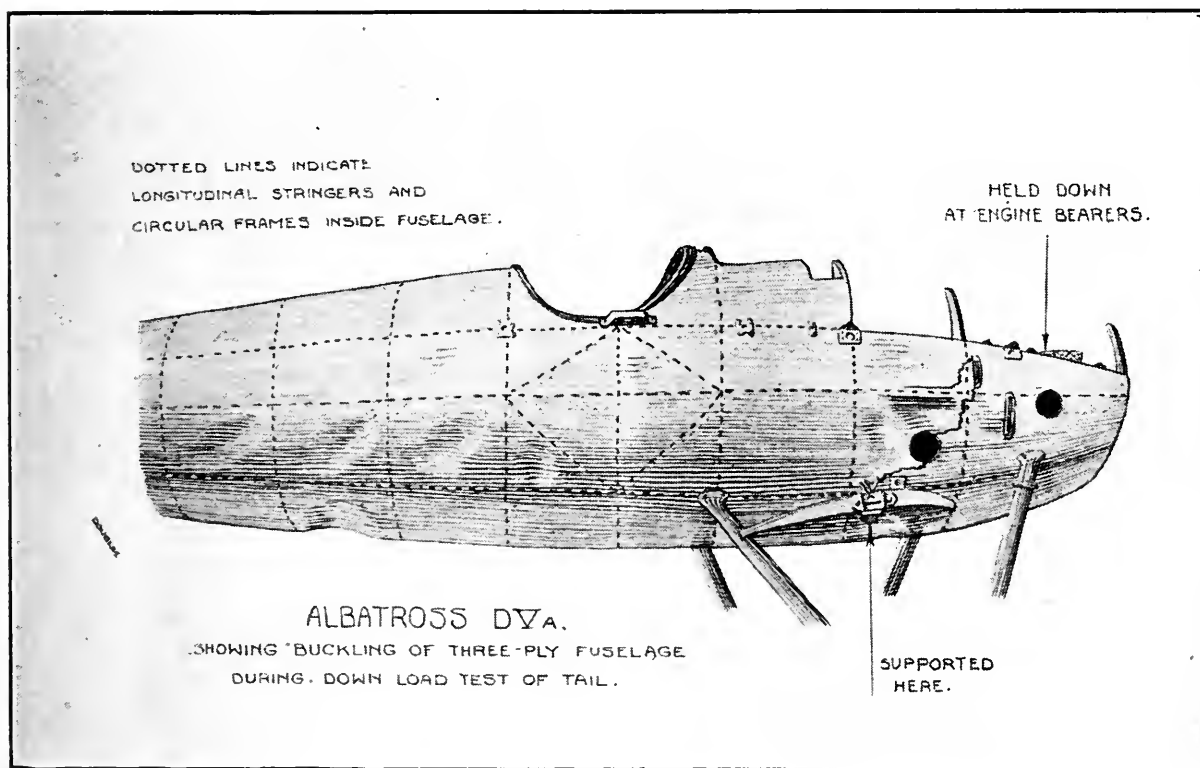


FIG. 25.—*Distortion of monocoque fuselage.*

A pure torsion test is frequently made in which the fuselage is secured (against torsion) at some section near the attachment of the rear spars and is subjected to two forces symmetrically applied to the rear spar of the tail plane on opposite sides of the machine; the forces acting in opposite directions and thus constituting a simple couple.

A method of applying these forces is shown in Fig. 26.

The rotation and distortion of several cross sections of the fuselage may be measured.

Undercarriage.

A full consideration of the various conditions of stress which may be experienced by an undercarriage during landing is somewhat outside the scope of the present paper. A few typical cases only will be considered. The probable limits of variation of the direction of landing reactions in the fore and aft vertical planes applied to the axle through the wheels may be represented by the conditions of (a) a landing which has been successfully "flattened out" and (b) a "pancake" with no forward component of velocity.

In Fig. 27 are shown the reactions for a case intermediate between (a) and (b). When the wheels first touch the ground the machine will have a velocity V along a path making an angle ϕ with the horizontal. For convenience this velocity may be considered as resolved into its horizontal and vertical components. As the machine moves forward the flexible parts of the undercarriage are compressed and the vertical component of the velocity is reduced. The wheels at first contact are not rotating and there must necessarily be slipping between the tyres and

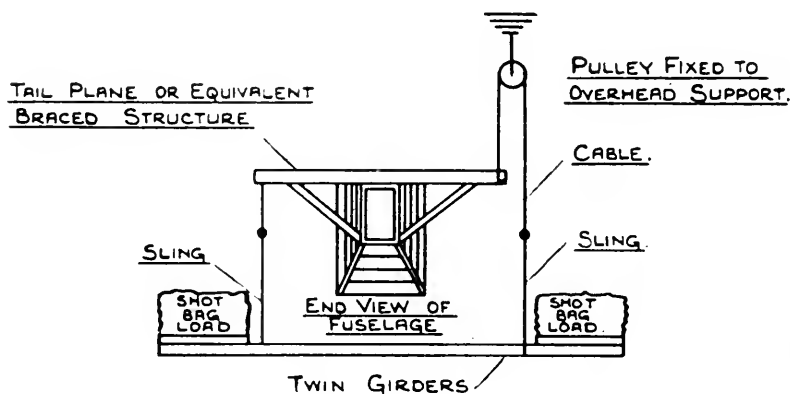


FIG. 26. TORSION TEST OF FUSELAGE.

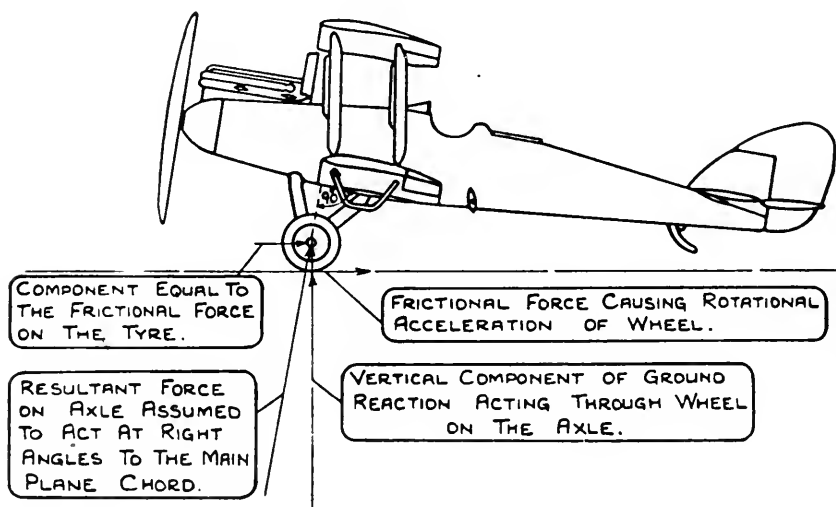


FIG. 27.
DIAGRAM OF LANDING FORCES ASSUMED FOR TEST.

the ground. The wheels will commence to revolve and will gain speed quickly, but slipping will persist until the peripheral speed of the tyre is approximately equal to the forward component of velocity. The stage at which this slipping will cease and the maximum frictional force which will act on the tyres will depend on many factors of which the principal are:—

- (a) Vertical and horizontal components of velocity.
- (b) Mass of machine.
- (c) Characteristics of shock absorbing parts.
- (d) Polar moment of inertia of wheel and tyre.
- (e) Coefficient of friction between tyres and ground.

It is of interest to calculate maximum friction forces for various assumed landing conditions, but unfortunately no reliable values for the coefficient of friction between tyres and aerodrome (or other) surfaces are available. Some simple

experiments made at the R.A.E. using light loading and grass surfaces indicated a value of about 0.64. Assuming values of this order we get for a machine of total weight 3,000lb. the following total horizontal forces acting on the wheels before slipping ceases.

Vertical component of landing speed. ft. per sec.		Assumed coefficient of friction.		Max. value of horizontal force. lb.
3	...	0.3	...	876
—	...	0.7	...	2044
15	...	0.3	...	4380
—	...	0.7	...	10220

The forces on the axle may therefore include a large horizontal component and the resultant will then be inclined backwards to a considerable extent.

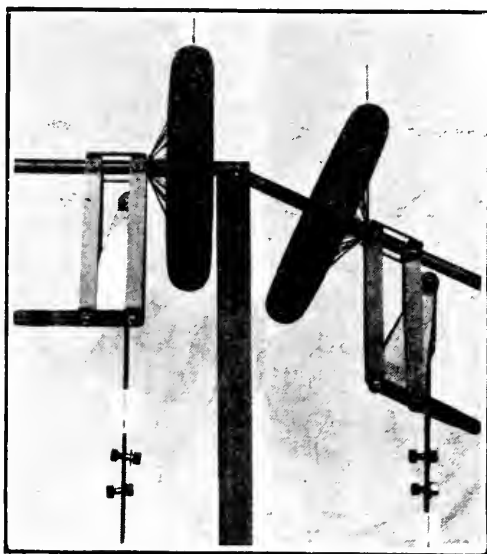


FIG. 28.—Axle test apparatus to represent effect of wheel inclinations.

In case (b) the rotation of the wheels is a negligible factor and the direction of the reaction may be inclined forward.

Superimposed on these conditions may be unequal distribution of load between the wheels due to landing wing down or on sloping ground and lateral forces due to drift or yaw.

The direction of resultant load on the undercarriage at any instant may therefore vary within wide limits. Certain particular cases are assumed for test purposes, and where one test only is to be made, it has been the practice to apply load so that the resultant force acting on the axles will be normal to the chord of the bottom planes where the latter are attached to the fuselage.

Static tests are made by applying load to the axles, the fuselage being inverted and mounted with the chord of the bottom planes horizontal.

Where the stiffness and strength of the axle for a machine of the usual conventional type are to be demonstrated, it is necessary that the points of application of the load should travel outwards with increase of load to represent the effect of the splaying of the wheels during landing.

This can be effected by the use of a simple link mechanism such as that illustrated in Fig. 28. Such a construction is stable in use and operates satisfactorily.

It is usual to measure distortion of the axle and extension of the shock-absorbing devices and also to observe closely the behaviour of the various joints, struts, etc.

The general arrangement of a static test of an undercarriage is illustrated in Fig. 29.

Dropping tests.—The accuracy of the results obtained from static tests of undercarriages is sometimes questioned on the basis that the time element is important. Where hydraulic or pneumatic energy-absorbing devices are fitted, the effect of rate of loading is all-important and static tests are, of course, useless. In such cases dropping tests may be made.

A simple form of dropping test may be arranged by attaching the undercarriage (either whole or in part) to a hinged pair of shafts as shown in Fig. 30.

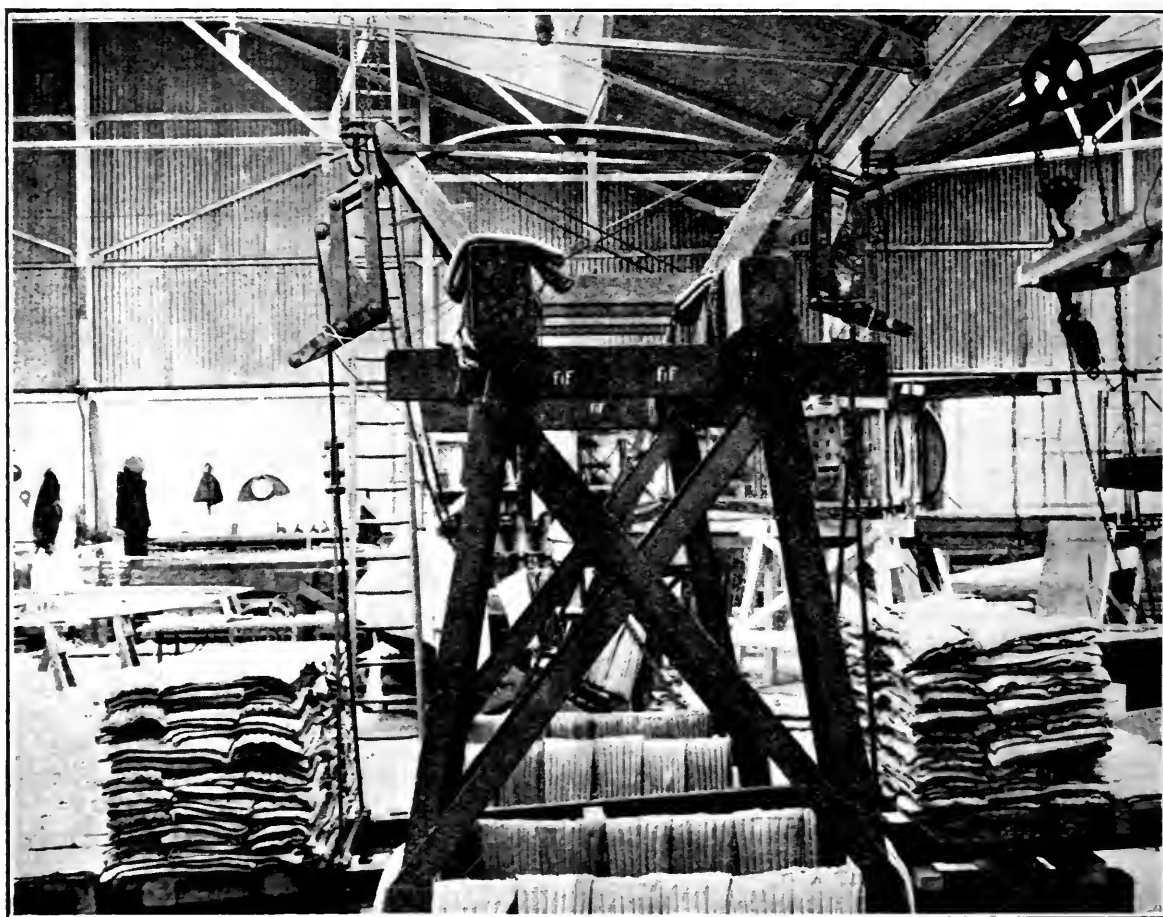


FIG. 29.—Static test of undercarriage.

These are arranged to swing about a pivot "A," and provision is made for a load of shot bags to be placed (at "B") over the wheels so that the static load on the latter is equal to the normal weight of the aeroplane. The whole may be lifted by suitable means and dropped by a quick release "C." The impact of the wheels is usually received on strong platforms which can travel on rollers in a direction parallel to the axle, thus allowing the wheels to "splay" as the axle bends. It is, unfortunately, impossible to calculate for the wheels at any instant during landing, their exact inclination to the vertical planes parallel to the direction of flight, on account of the imperfect data available, but it appears probable that in most undercarriages of the type under consideration, the wheels are not only free to splay (*i.e.*, no lateral forces acting on the tyres) but may even be subjected to forces tending to increase the splay, due to bending of the

axle in a horizontal plane causing the wheel tracks to diverge. The use of rolling platforms, however, is simple, and is probably a close approximation to typical cases.

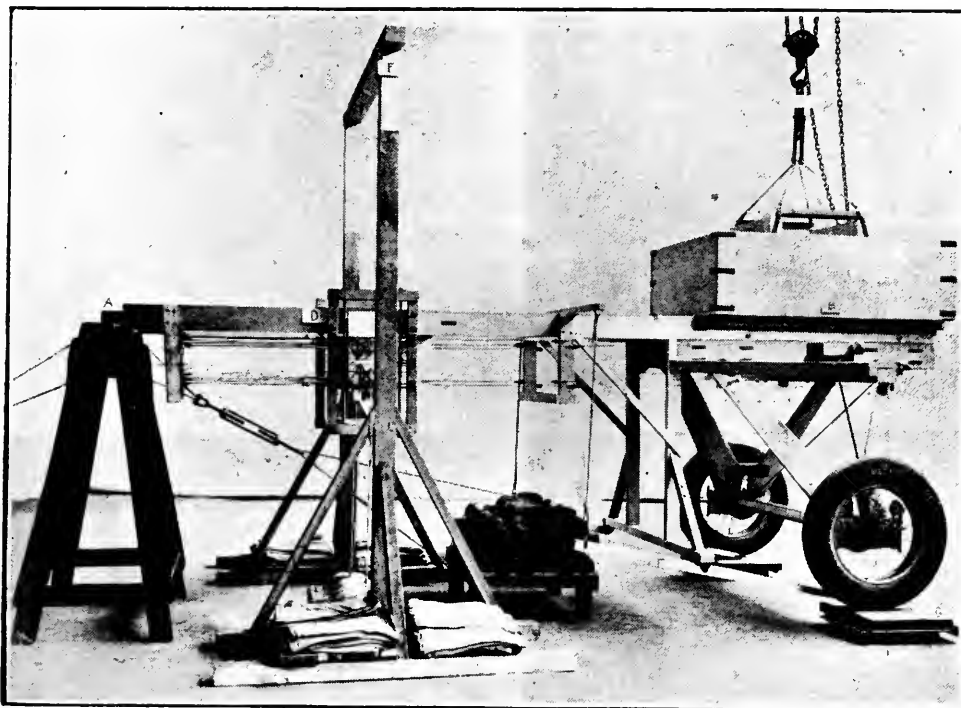


FIG. 30.—Dropping test of undercarriage.

During the actual drop it is somewhat difficult to observe and record the relative distortions of the various parts of the undercarriage at different stages of the action. One method is to use autographic record, taking suitable precautions to prevent errors due to deformation of parts under the high acceleration forces. Autographic apparatus is illustrated in Fig. 31.

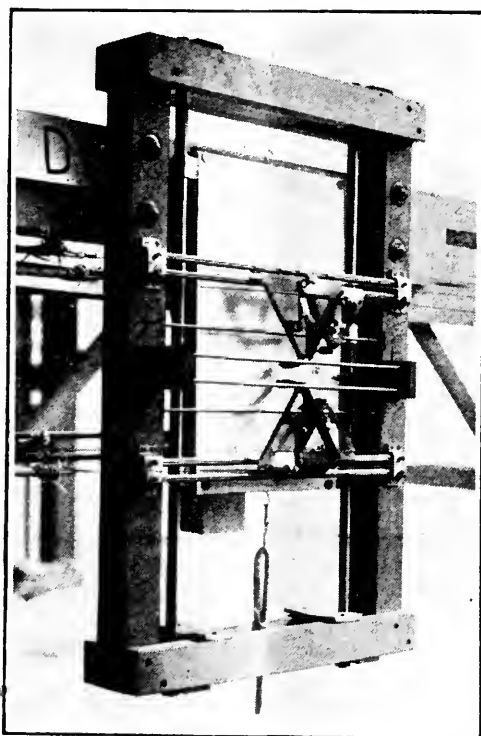


FIG. 31.—Autographic recording of distortions during impact.

In the case of energy-absorbing devices, where the time rate is of vital importance, it should be remembered that a dropping test as described above does not accurately reproduce the conditions which occur during actual landings, even though it be arranged that the vertical component of velocity at impact be the same in the two cases. This is because, in a normal landing, the lift on the planes during the event is approximately equal to the weight of the machine, and for purposes of test the machine should be considered as a body having a mass and a vertical velocity equal to those of the actual aeroplane, but having little or no weight.

It is possible to devise a form of test which will represent those conditions, but the expense will hardly be justified, as the results obtained from the ordinary dropping tests will not be much in error.

Rib tests.—The tests of the main planes described above do not determine the strength of the ordinary ribs since the load is applied directly to the spars. Supplementary tests are therefore necessary.

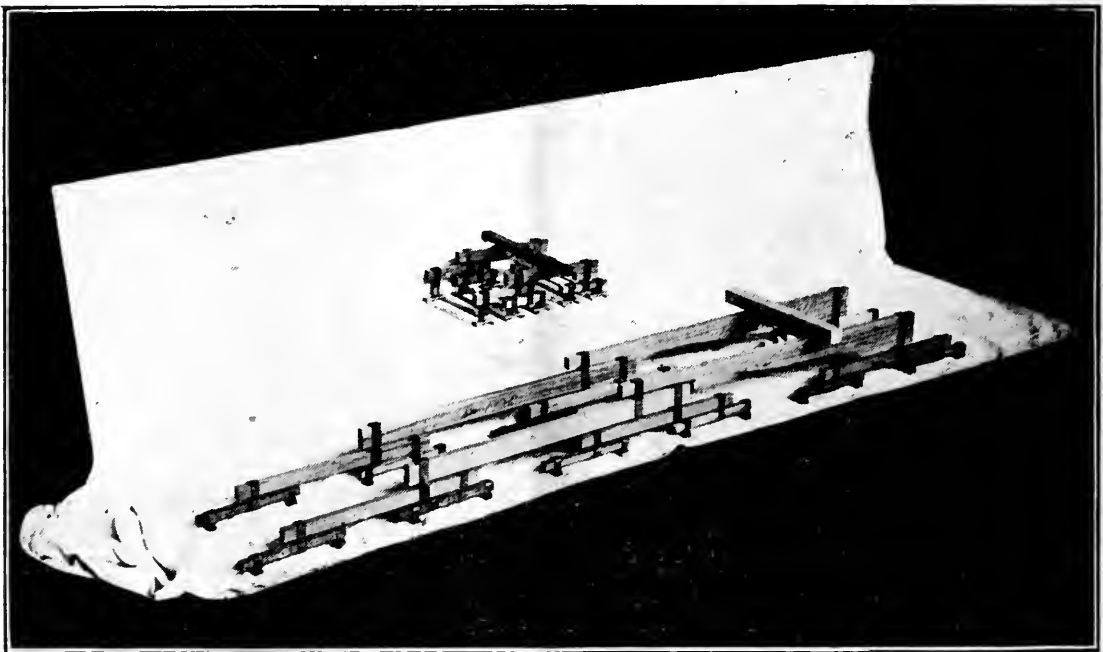


FIG. 32.—*Pivoted levers for rib test.*

The chief difficulty lies in deciding the distribution of the loading on the rib. This is influenced by three main factors:—

- (a) The distribution of air forces.
- (b) The re-distribution of these forces through the medium of the fabric (or other covering) to the ribs, either directly, or through the leading and trailing edges.
- (c) The stresses introduced by the initial tension of the fabric.

For the purpose of test, the distribution of air forces must be chosen on the basis of the best data which may be available for the particular or similar wing sections. The stresses introduced by the initial tension of ordinary doped fabric are considerable, but cannot be estimated with any accuracy, and the safest method of allowing for the effect of these stresses is to reproduce them by covering a test section of plane, taking precautions to ensure that the dummy end ribs are very stiff so that the flexibility in the direction of the span compares with that of a full-size plane.

If load could be applied to the surfaces of the plane distributed like the assumed air forces, a satisfactory test could be made, but unfortunately there is

no simple method of loading a surface (itself curved and somewhat flexible) according to a predetermined distribution, which usually includes some steep load gradings.

At the same time it is extremely difficult to calculate the distribution of stresses in the covering of a plane subjected to air forces, and assumptions must again be made to simplify the process of estimating the distribution of forces on each rib due to the air loading on the fabric. The method of calculation usually adopted for this purpose and the method of applying load to two ribs during test by a duplicated set of levers is described in Advisory Committee for Aeronautics Reports and Memoranda No. 344. The adjustment of these levers has, however, been simplified by the use of the pivoted fittings shown in Fig. 32. An illustration of a typical rib test is given in Fig. 33.

An exceptional case occurs with the distribution of load on a plane (of section similar to, say, R.A.F. 14 or 15) flying at high speed and small angle of incidence. In this case the approximate distribution of normal air forces is

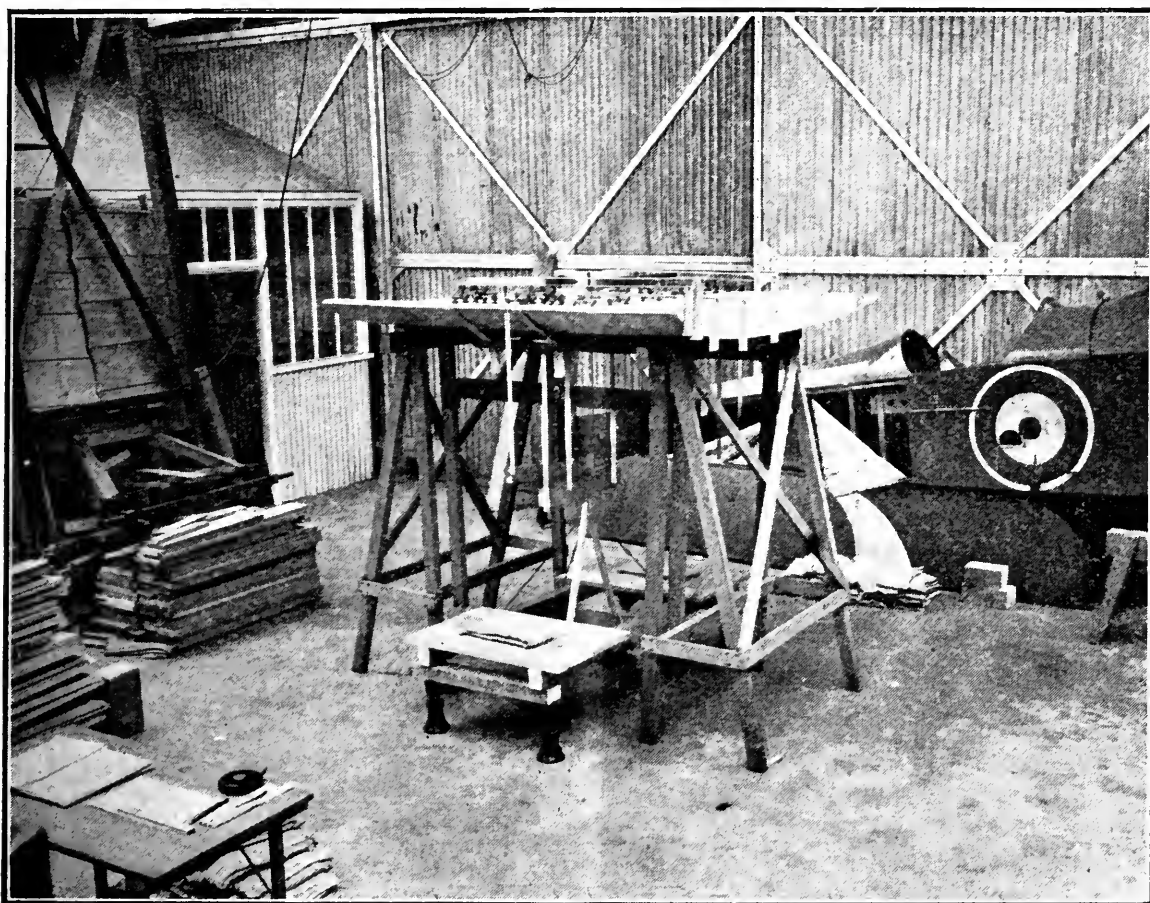


FIG. 33.—General arrangement of rib test.

shown by the full line in Fig. 34. Assuming that the static pressure in the plane is determined by the vent holes and that the latter are on the under surfaces at or near the trailing edge, it will be seen that the air forces on the top surface are considerable, but that those on the bottom surface vary from positive to negative and are nowhere of great magnitude. No serious error will be introduced if, for test purposes, these small air forces on the bottom surface be added algebraically to those on the top surface as shown by the dotted line in Fig. 34.

It will also be seen that the grading of the load is nowhere very steep. Under these circumstances the test may be made by inverting a section of plane,

supporting at the spars, removing panels of fabric from inter-rib spaces on the bottom surface, and applying a load of loose shot to the top surface.

The distribution of the shot may be effected with sufficient accuracy by dividing the loading space into cells and placing calculated amounts of shot in each cell at each increment of loading. It is not intended to encumber this description with details of the technique which has been developed and adopted for facilitating the process of loading, but it may easily be imagined that the speed, accuracy and general success of the test depend largely on the employment of methodical and simple methods which may largely be reduced to a matter of routine.

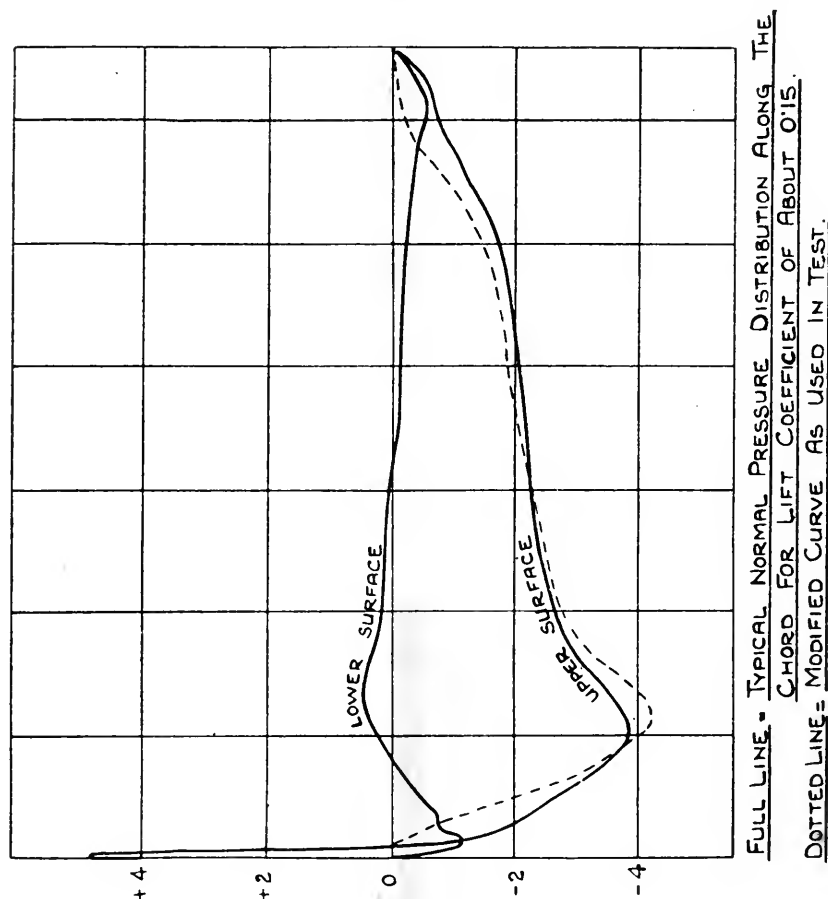


FIG. 34.

PRESSURE DISTRIBUTION ASSUMED FOR RIB TEST
TO REPRESENT CONDITIONS OF HIGH
SPEED FLIGHT.

Shot Bags.

The type of shot bag employed at the Royal Aircraft Establishment has proved so satisfactory in use that a short description may be of interest.

The weight of each shot bag is 25.0 lb.

The strong fabric case ("No. 8 fell canvas") is divided into a series of longitudinal compartments by rows of stitching $1\frac{1}{2}$ in. apart. These, when the case is filled with shot, give the whole a ribbed appearance and prevent any motion of the shot particles. The overall dimensions of the open shot bag are about 36 in. by 8 in. By leaving a zone free from shot midway along the length, the bag can be folded so as to occupy a space about 18 in. by 8 in. by 1.38 in., the latter being the average vertical height of each folded bag in a pile.

When a concentrated load is being formed, it is inadvisable to allow the height of the pile of shot bags to exceed the smaller dimension of the base on which it is formed. Since shot bags have an aggregate weight of about 218 lb. per cubic foot, or occupy 4.6 cubic feet per 1,000 lb., the size of platform necessary for any given load may easily be determined.

For stability of the load it is advisable that the pile of bags should be "tied" by altering the direction of "lay" of each succeeding layer.

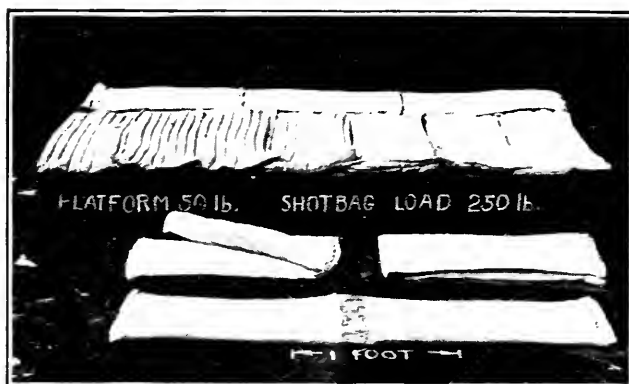


FIG. 35.—*Shot bags.*

The dimensions of loading platforms should be so proportioned as to allow of suitable arrangement of the bags. A typical platform is illustrated in Fig. 35.

A larger number of alternative arrangements would be available if the breadth of the shot bag were some even multiple of the length.

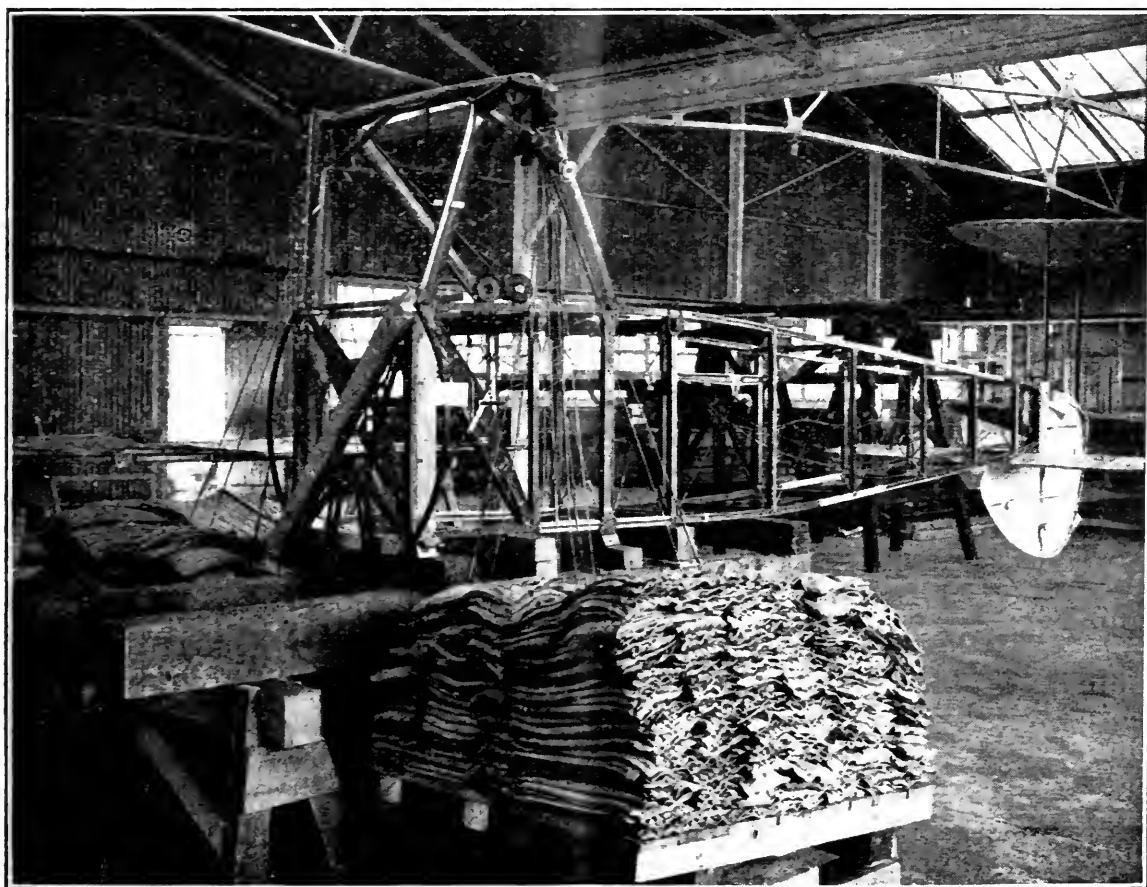


FIG. 36.—*Shot bags as concentrated load.*

The volume occupied by a concentrated load may be visualised by the aid of Fig. 36, which represents a comparatively early form of undercarriage test. The pile of shot bags in the foreground has a weight of 6,500 lb. or 2.9 tons.

Where large concentrated loads are employed, it is necessary to take certain precautions to ensure the safety of the personnel. Where possible, the loads should be kept near to the ground. Where this is not feasible, timber, or other supports, should be arranged to prevent any large displacement of the load at the time of collapse of the structure. An endeavour should be made to provide not merely for all likely, but for all possible, forms of failure in the structure. A clear open space should always be provided to ensure a quick line of retreat in case of emergency, and it should be remembered, when deciding the clearance between the load and the safety supports, that during the collapse of the structure the load may only subside locally and a very small inclination may be sufficient to start slipping of the pile of shot bags.

The paper having been read, the CHAIRMAN said it was a valuable document to be added to the many interesting records which existed in the Society's Journal, and he was sure it had proved instructive to those who had listened to it. He called upon Dr. Sutton Pippard to open the discussion.

DISCUSSION.

Dr. SUTTON PIPPARD agreed that Mr. Douglas's paper would be of extreme value in the records of the Society. To have at first hand Mr. Douglas's ingenious methods for testing aircraft would be of great value to all interested in structural work, and also to students working on the subject. Destruction tests seemed to fall into two distinct types. There was the first class of a more or less routine nature made on a particular type of aeroplane to determine how it behaved, or how it might possibly behave, during its career. The strength of the main structural parts of such an aeroplane could be calculated with a fairly high degree of accuracy, but there still remained the question of fittings, and the occurrence of failures which it was impossible for the designer to foresee, and in the majority of photographs shown that evening it was evident that that type of failure had taken place. That class of test was also extraordinarily valuable for dealing with unusual structures. Mr. Douglas had referred to some tests he made for the nose-diving case, in which there was an extraordinary condition of loading, and he (Dr. Sutton Pippard) remembered him putting up that test for a particular structure which it was almost impossible to calculate. He had put up the test on the actual machine and had shown its actual strength. That was an extremely valuable test, and he was glad it was on record as an official publication. Then there was another thing that the tests had brought out, and that was the variation of flexibility of the structure, which was important, and could not very well be calculated. Reference had been made by the lecturer to the readings that were taken during the course of the tests on the deflection in the plane spars and the bowing of the plane struts. Mr. Douglas must have an extremely valuable collection of that data, and he (the speaker) was wondering whether use was being made of that, or whether it was just filed away. The time had now come for a very careful analysis of that data to be made. In addition to those tests, there was a class of test which actually fell under the heading of research, and was specially typified by the question of undercarriages. The undercarriage question was an extremely wide one, and a

good deal of what Mr. Douglas had said might be open to argument. In any case, research on a big scale was required before the design of undercarriages could be put on anything like the same basis as the design of other parts of the structure. The static test was arbitrary, and, as Mr. Douglas had said, practically useless in the case of some energy-absorbing devices. On the other hand, the dropping test did not appear to him (the speaker) to be over-satisfactory. If one happened to hit on the right drop, which just caused failure of the undercarriage, it was something definite; but if one increased the drop step by step it could not be said what the actual strength was before the test was begun, and that was what was required. Another point was that in testing, Mr. Douglas allowed one-seventh of the lift forces for drag for all centre of pressure conditions. He believed that this was not quite in accordance with the method used in calculation. It would be interesting to know whether the official calculation methods and official test methods were slightly at variance on that point. With regard to the second slide of failures shown by the author, in which the spars collapsed sideways together, he would like to know whether the author had found that type of failure at all frequent. He had only known it to occur twice—once on a very old type of quadruplane, and once in a deliberate test he had made in order to get that condition. In the particular case shown, he believed the fabric would have been a distinct advantage had it been on. He again thanked Mr. Douglas for his paper.

At this point, the CHAIRMAN suggested that the Secretary should be asked to write round to a number of designers of different aircraft asking them for written contributions to the discussion. He would very much like the discussion to be a full one, and the record of the makers' views would be of great value to designers and to people who had to test aeroplanes hereafter, and would probably be welcomed by the Air Ministry and the Royal Aircraft Establishment.

The suggestion met with approval.

Mr. McKINNON WOOD congratulated Mr. Douglas on the very clear way in which he had given the account of his work. There was no one who could speak on structural tests so well as Mr. Douglas, because he had practically a monopoly of that kind of work. Some of the illustrations served to give an idea of the amazing ingenuity he brought to bear on the invention of gadgets and apparatus for this sort of test. To realise it to the full, one had really to go to his Department at Farnborough and see the wonderful gadgets he had, some of which were extraordinarily simple in construction, and that was where he showed his real skill. With regard to undercarriage testing, we were still very much at the beginning, and he was inclined to think that in the design of undercarriages also we were still in the early stages. The improvement of undercarriage design depended upon the development of methods of testing. There were a great many things in connection with undercarriages about which we knew very little; in fact, we knew very little about what happened when the aeroplane struck the ground. He had tried to get some information as to the effects of landing with drift on the forces on the wheels, whether the side force on the wheel was independent of the angle of drift, or how it depended on this angle, but he had been unable to reach any conclusion. We wanted to know under what conditions tyres were torn off wheels. He seemed to remember having been told by a tyre designer that the tyres could not be torn off, but that the wheels would collapse first, but tyres do come off. There were a great many points of that nature on which information was wanted, and we should have to settle down and develop apparatus for testing undercarriages out in a way which would really represent a landing. It might be a complicated piece of apparatus, but he believed it quite likely that it would be developed.

Mr. W. O. MANNING said it would be a very good thing if more illustrations of those peculiar types of failure could be circulated for general information.

For instance, some peculiar type of failure might happen to one machine, and it would be quite well known to those at Farnborough, but unknown to those who were designing aeroplanes, and the fault might be repeated. Also it had struck him forcibly throughout the lecture how many assumptions had to be made in the calculation of various forces. Various testing establishments had now been going on for 10 or 15 years, and yet we knew nothing of pressures on the fin or on the rudder. The same thing applied to a very large number of other aerodynamic forces on a machine. This fact was illustrated very forcibly by the number of assumptions which the lecturer had to make.

The paper is one of very great interest, the cases of failure shown all deserve the careful attention of those engaged in design, and it is difficult to rate too highly the ingenuity shown in devising the various tests.

Colonel W. D. BEATTY congratulated the lecturer. There was one thing upon which he had been too modest to lay stress, and that was the very large amount of work that must be involved in reducing the various tests to a simple form. The lecturer must have burned the midnight oil in reducing those tests to simple form.

Miss HUDSON pointed to the extraordinary value of the demonstration of these practical tests to beginners. For the first six months of her own intercourse with aeroplanes, she either had to study objects which were miles up in the sky, or else blue prints, and the first time she had ever got to close quarters with an aeroplane was in Mr. Douglas's hangar at Farnborough. To see the various classes of failure actually happening, either slowly or suddenly, certainly added enormously to one's knowledge. If only for the sake of students, the Department at Farnborough ought to go ahead. Of course, that was a comparatively unimportant part of its work, but it was really of very great value. In conclusion, she wished Mr. Douglas had shown a great many more pictures, but hoped he would give another series at a later date.

The CHAIRMAN proposed a vote of thanks to Mr. Douglas, which was carried with acclamation.

Continuing, the Chairman said that Mr. Douglas had put so much brain work into this science that he had perhaps forgotten that a very great deal of strenuous effort was put into it before his time. The only thing in the whole Paper which he could criticise was the Author's suggestion that the first figure was an indication of the procedure up to 1916. He remembered that in 1912 the first group of shot bags divided by a gap for folding were made by Mr. Cody at Farnborough. In 1912, 1913, 1914 and 1915 they used a cathetometer and dummy level to measure deformations with each increment of load. He was quite sure that if Mr. Douglas had been there he would have improved very much on their procedure, but there was a great deal of work done by men whose names were well known. It was not specialised, and it had suffered from that fact. It would be remembered that Major Green, the late Lieutenant Busk, Major Grinstead and Captain Mayo, and others, did a great deal of work, such as in the extension of deformation tests, and they very carefully investigated the stresses and strains that came upon aircraft in those early days. With that single criticism, which was meant in the kindest sense, because he looked upon the paper as quite a record one, he repeated the thanks of the meeting for the very excellent paper presented.

Mr. DOUGLAS, replying to the discussion, in the first place thanked the meeting for its patience. With regard to Dr. Sutton Pippard's remarks, he had referred to lateral failures of spars, and had mentioned two cases. He remembered, off-hand, two other cases, but they were both in planes of similar type. In one of those cases the test was carried out with and without new fabric, and the trouble did not occur with new fabric, but did occur when there was

no fabric. The open question was whether it would have occurred had there been fabric which was ageing. That was still an open question, but it was generally agreed that they should not rely too much on the bracing effect of the fabric to prevent that type of failure. In connection with the proportion of lift to drag at stalling incidence, the figure of one-seventh had more or less been blessed by use for a long time, and had been founded on the best information available up to very recently. The error was very small at present, and they were rather waiting for the results of some full scale tests in the air, which were almost ready, before making any drastic change in their method. Mr. McKinnon Wood had expressed alarm at the figure of 10,220, but he (the author) had pointed out that with such a downward velocity (15ft. per second) the machine would probably crash anyhow, and the figure was only of theoretical interest in that case. His figure referred to a particular undercarriage with particular characteristics, but was fairly typical. Mr. Manning had mentioned that there seemed to be rather a lot of assumptions throughout the Paper. That was partly because he (the Author) had taken some trouble to emphasise the assumptions where he could. It was always a safe plan to have before them clearly what assumptions were being made, otherwise, from force of habit, they were liable to forget that they were assuming things and that those assumptions were not always necessarily correct. Also, the assumptions arose in several different ways. They had to assume something generally in deciding what loading probably went on the part under consideration, and they had to assume something occasionally because they could not represent that exactly in their tests, and when the assumptions were all added up and tabulated they did appear to be numerous. Colonel Beatty had referred to the amount of work probably involved in the elaboration of some of the tests. Of course, there had been a lot of work involved, and during the war it meant burning some midnight oil, but he must mention the very able staff that had helped him all the way through, and especially Mr. Clegg, who now looked after the tests almost entirely. The Chairman had suggested writing for the views of designers of prominent aircraft companies on these tests. Such information, if it could be obtained, would be very valuable to those at Farnborough, because they were not always sure, when designers paid them visits, whether they really said what they thought; but, in general, designers and visitors agreed largely with their methods. When they were introducing a special test or a new method they tried to notify the designer concerned beforehand, so that if he did not approve of their methods he could say so in time; but as a rule, he was glad to say, designers approved. The Chairman had also referred to the fact that a large number of the present methods were in existence as far back as 1912. He (the Author) had no wish to suggest originality for present methods, but merely wished to describe them. A lot of these tests, round about 1912, had hardly been reduced to anything like routine work, he believed; they were mostly special laboratory tests, but in many cases present methods had been adopted from those pioneer tests.

The meeting then closed.

Mr. C. C. WALKER (*communicated*): That part of Mr. Douglas' Paper which deals with typical cases of failure is of great interest, and at the risk of seeming greedy when hearing so much of value, an expansion of this part of the Paper would surely have been greatly appreciated by everyone. Mr. Douglas's experience must be unique, and the more obscure types of secondary failure which he has witnessed would be of the greatest interest to aircraft designers. It is difficult to over-estimate the value of the earlier tests to destruction in directing attention to the causes of secondary failure. Once the way in which rather complicated joints were liable to distort had been indicated, it became possible to carry out detail tests on materials and combinations of materials

such as occur when metal has to meet wood under stress, which could form a more certain basis on which to design.

Full-scale strength tests are now practically impossible for aircraft constructors to carry out, and it is to be hoped that it may be found possible to continue this work at the R.A.E. on modern aeroplanes.

There is one point on which information would be extremely useful, and that is the strength of old and much used aeroplanes. Mr. Douglas has, I believe, carried out at least one test on an old machine, but as he did not touch on this in the Paper there was probably no result obtained which was attributable to age.

It must now be easy to obtain military aeroplanes at practically no cost without the engine, of a type which has already been tested new. If it is difficult to obtain a machine with a large number of flying hours behind it, one might be pegged down in the open for three months, or say 2,000 hours exposure to the elements, merely taking the necessary steps to avoid rust or standing water in any part, and afterwards tested to destruction.

It would be a further advantage if a machine could be selected which employed 3-ply wood for structural purposes to some extent.

I should like to press strongly the desirability of such a test, and to ask Mr. Douglas if he has any information on the subject.

As regards testing wings for the terminal dive condition, the application of load to the front spar seems an approximation which is hardly justified, as it is probable that the leading edge or the fabric at the leading edge would be the first thing to go. In any case as usually taken, *i.e.*, a terminal dive without a propeller, the condition is somewhat unreal, and of little practical importance, except as a convenient means of distributing the loads for the purpose of stressing tails, fuselages and perhaps rear spars.

What may be termed self-intensifying stresses due to unstable deflections (*e.g.*, increase of incidence) are difficult to estimate, and only a limited amount of help is to be obtained from strength tests. I believe it is the fact that static tests were carried out at Farnborough to try to account for certain failures of this type without success.

Mr. Douglas is to be congratulated on presenting a Paper which is a record of such valuable, thorough and accurate work.

Mr. E. G. WALKER (*communicated*): Mr. Douglas gives, in his Paper, a fairly full account of the methods employed at the Royal Aircraft Establishment in testing aircraft to destruction, but he says little about the interpretations which are to be placed on the results of his tests. This appears to the writer to be a phase of the subject which might well be discussed at further length. The destruction of a completed machine straight out of the shops seems, on the face of it, to be an expensive and relatively crude way of testing the fitness of a design, and unless results commensurate with the expenditure and waste of material and labour involved can be obtained, its value may well be open to doubt. It by no means follows that a detail which will stand up satisfactorily to a static loading test of the sort described in the Paper will do so when subjected to the entirely different stressings which obtain under working conditions. An aeroplane in flight may be subjected to much more severe stress conditions than when loaded statically, and its safety involves the consideration of such points as range of stress, time rate of variation of stress, shock, vibration, etc., all of which may produce considerable modifications in the ability of any particular member to carry its working loads. It is obviously impossible to reproduce any of these effects in a static loading test, although, as Mr. Douglas points out, a certain amount of work in this direction has been done in the case of undercarriages. In addition, in many cases the distribution of static load is only an approximation, more or less close. Evidently the effect produced on

any particular member by such a test may only be remotely connected with failure-producing effects in that member under working conditions. Hence considerable caution is necessary in interpreting the results of static tests on aeroplanes. The Author might well supplement his Paper by a statement of what his experience leads him to consider the results of static tests to mean when applied to a machine as loaded under flying conditions.

Mr. B. THOMPSON (*communicated*): Mr. W. D. Douglas's Paper on "Destruction Testing" is a valuable record of the methods at present in use, and of their development. It is therefore the more to be regretted that he has put on one side the whole question of the nature of the air loads coming upon the surfaces of aircraft, since both destruction testing and calculations are useless or the reverse in exact ratio to the accuracy of the assumptions made in respect of these loads.

That the assumptions now made are reasonably correct is shown by the small number of breakages due to normal flying, including stunting, on aircraft built to British load factors. On the other hand, there exists more than a suspicion that these load factors are higher than is necessary for commercial aircraft, and some form of destruction testing that will more closely simulate the dynamic loading of flight conditions seems desirable.

I believe efforts to secure a dynamic loading have been made in the U.S.A. by testing ribs and fabric under water, a section of a plane being mounted under the travelling carriage of a ship model testing tank, and the speed at which collapse occurred noted. The unsatisfactory point about any test of this nature is that the destruction is too complete.

In respect of the surface distortion of monocoque fuselages under load, I would like to know if any experiment has been made in painting such a fuselage in black and white bands or in chequers and photographing it from different angles during the test. As an application of the old gunmaker's method of testing rifle barrels for straightness it might be of interest.

Mr. J. D. NORTH (*communicated*): I am glad to have this opportunity of publicly recognising the valuable work on structure testing for which Mr. Douglas has been responsible. No one reading his Paper can fail to appreciate the conscientious accuracy which has marked his experiments. I am glad to say, however, that though in this country we are well to the fore in the scientific testing of structures, we have not thought a destruction test of a complete aeroplane an essential preliminary to the public use of that machine. If such a regulation were introduced it would throw on the introduction of new machines a financial burden too great to be borne at present.

I feel that testing to destruction is most usefully employed in checking assumptions made in certain complex cases in structural design. A careful examination of detail arrangements, such as is necessary where a detailed check on the strength is to be kept, reveals cases where the designer or his assistants engaged in the work of checking cannot feel confident that the simple engineering approximations possible will give a reliable indication of the strength of the component or detail. Here we have a proper subject for destruction testing which, if properly carried out, will provide a basis for future design, apart from the special verification for which it was intended. In many cases it would be useful to carry out series of tests varying one condition of the complex at a time, in order to furnish a proper relation between cause and effect.

In the early stages of light metal construction a considerable amount of testing has been necessary, but the accumulated data renders possible more and more confident prediction. While design is kept within the boundaries allowed by reasonable deduction from experimental evidence available, it is possible to

economise in test work; but when it is desired to go further afield, experimental aid must once again be called in.

Destruction testing should, I feel, be used as an instrument of research rather than as a mere process of checking. It is true that, in research, experiment is intended to answer a definite question and is not conducted in a haphazard manner; but if destruction testing furnished no more information than that the article tested withstood specified loads, it would not be used to its best advantage.

Mr. Douglas's Paper refers specifically to testing to destruction, but he will, I am sure, agree with me that destruction is not essential to useful testing. In undercarriages in particular testing is required to verify the *assumptions* made in calculation and to improve the technique of design, rather than to measure the load at which a particular undercarriage will fail.

I believe that Mr. Douglas holds the same views, and I trust that he will have adequate facilities to extend his useful work in other directions and on broader lines.

Mr. H. P. FOLLAND (*communicated*): I cannot but endorse the advantages of a Paper such as that of Mr. W. D. Douglas on the testing of aircraft to destruction. It so clearly puts forward the methods of testing, and the results which can be obtained; also the method of testing which gives a result under conditions closely allied to those in flight.

Testing to destruction is all-important to commercial aviation. Under the present conditions of commercial aviation it is vitally essential that tests on a new type should be carried out under the R.A.E. method of testing and procedure. The standard method of checking the machine by the Calculations Department of the Air Ministry does not cover the complete aeroplane, and does not find out the weak spots of the detail design. In many cases the machine is checked chiefly from the point of view of main structure of wings, tail plane and fuselage. Only in very rare cases are the fittings themselves checked in detail and for design generally. It appears to be sufficient to give the loads of the principal members of the structure and to ignore the detail design of the fittings. In many cases in the past machines have been stressed and checked, and yet in flight fittings have been broken, or have collapsed through faulty detail design. Therefore, I am of the opinion that it is absolutely necessary, especially with commercial machines, that one machine at least should be tested to destruction, before any machines are used on a commercial air line, unless they are of a similar design to a type already shot-loaded.

The question of testing materials and joints by means of X-rays has proved extremely useful, and should become vitally important. One use of the X-ray process appears to me to be that of examination of commercial machines after a large number of hours flying. It is necessary, after certain periods, to renew airworthiness certificates. This is generally done by A.I.D. inspection. It is invariably considered too long and too expensive a job to take the whole of the fabric and fittings from the wings, etc., for proper internal inspection. It would, therefore, be useful if some sort of portable X-ray apparatus could be used for the inspection of fittings after service or commercial use; it would then be possible to find out whether joints were standing up to their required work, or were showing any signs of weakness.

Another case which should be considered more carefully is that of initial tension. It is quite possible that calculations will show very little load in certain members, and in other cases some members are redundant.

In redundant members, and in members lightly stressed, there is often a greater load applied due to initial tension, resulting from the trueing up of a wing structure of the fuselage. It is possible to get in the so-called redundant member a load equivalent to 75 per cent. of the total strength of the trueing-up

wire. It would, therefore, be useful to take readings from a tension indicator placed on the redundant bracing wires or lightly stressed wires, then tension up the wire to give a load equivalent to, say, three-quarter strength of the wire, and then make an examination of the resultant forces on the fittings and members adjacent. Over-tensioning of wires is found to cause trouble with fittings and struts due to the parts being calculated to meet the design loads instead of taking the initial tension which may arise from trueing up.

Mr. R. A. BRUCE (*communicated*): As a record of how far the science and practice of conducting such tests has been carried, Mr. Douglas's Paper leaves little to be desired.

It is of course well understood that destruction tests do not give all the knowledge which is required with regard to the possible methods by which an aeroplane can be destroyed by overloading. For instance, it is quite obvious that no light is thrown on the effects of wear and vibration.

With reference to the latter, a fair number of separate experiments have been conducted upon such subjects *inter alia* as to the effect of vibration upon the breaking strength of streamline wires. There is, however, a point of view which it may be profitable to give some consideration to at the present moment. Very simply expressed, the question to be considered is under what circumstances is it possible to indulge in the very expensive luxury of complete destruction tests upon an aeroplane?

There seems little doubt that such tests were fully justified (and could not be described without abuse of language as in any sense a luxury) whenever large numbers of aircraft of settled design had to be put into production. The aircraft industry, however, will recognise that it is two or three years since anything approaching this state of affairs has occurred, and we fear that it may be some years before it is repeated.

The question therefore arises as to whether it is not possible to attain a great deal of useful knowledge by a carefully considered system of applying shot-loading to a full-size aeroplane structure in such a way as to prove it without destroying it. The nearest analogy to such tests I have in mind are those which apply to Board of Trade or Lloyds tests on steam boilers. The application of the load is such as to cause stresses in excess of those normally encountered, but not sufficiently so to dangerously stress the structure. On the other hand, the deflections and yields under such proved load are very carefully noted, and if they exceed certain determined limits the structure is not passed. This may result in the structure being put right by additional staying, or it may call for complete rejection.

Would it not therefore be worth while to thoroughly investigate the possibility of applying a proof load, which should be some multiple of the normal flying load, of the order of 2 or 3, and carefully observe the deflections of the structure under these circumstances, and in particular the tendency of all fittings and attachments to distort? The object of this test would be to allow the aircraft, subject to careful inspection, to be utilised after such tests had been completed. In order to develop the necessary experience it is suggested that whenever aircraft are in future tested to actual destruction the load should be applied in defined stages corresponding with multiples of the normal flying load. A very careful survey for deflections and distortions should be conducted at the end of each multiple loading. The series of observations thus taken should then be carefully compared with the observations when rupture or failure takes place. The object of so doing would be to determine whether fresh light cannot be thrown upon the behaviour of the aeroplane structure when loaded with, say, three times the normal flying load, so as to reveal unsuspected structural weaknesses by the indications of abnormal distortion or deflection.

The importance of this resides in the actual practical limitations to aircraft construction imposed by the financial stringency of the country. No machines are being built in large quantities at the present moment. On the other hand, a fair number of experimental types are being produced in small quantities of three or thereabouts. It seems hardly possible at the present day to destroy one-third of the aircraft produced to learn whether they are safe. Some other procedure should therefore be adopted, and investigation should be conducted with a view to determining how far the kind of proof load advocated can be relied upon.

It may be objected that hesitation might arise in using aircraft structures to which such a proof load had been applied, but I do not think that such can be seriously entertained if the proof load is judiciously fixed with a view to limiting it to such a load as may be expected to occur on exceptional or rare occasions during the actual life of the aircraft considered.

It is not my purpose to make any suggestions with regard to the multiple of the normal load which should constitute the proof load, but it is clear that any machine which is capable of being looped may encounter loads of 3 to $3\frac{1}{2}$ times the normal flying load, and that if the proof load were chosen so as to coincide with about this multiple of the normal flying load, no greater harm could have been done to the structure in the stripped condition where every fitting can be observed than would be encountered by the aeroplane when subjected to this manoeuvre but without the possibility of examining the effects of the load applied.

Another point of some importance in testing aeroplanes to destruction arises in connection with the difficulty of applying the loads. The duration of the time during which a structure is subject to load is one of some importance. No doubt it will be within the experience of many constructors that in loading separate units to destruction a load which may be carried for a short time safely will, if the structure is allowed to stand for prolonged periods under it, ultimately cause failure.



NOTES ON THE STORAGE OF AIRCRAFT.

BY P. V. HOARE, A.F.R.A.E.S., A.M.I.C.E., A.C.G.I., D.I.C.

GENERAL.

Introductory Remarks.

The storage of aircraft is sometimes regarded as a matter of secondary importance, but to maintain good efficiency and reliability considerable attention must be devoted to the aircraft during the time when it is not actually in flying condition. Storage in an indiscriminate manner leads to a rapid deterioration, with a consequent financial loss and the introduction of other elements which may be exceedingly dangerous when the aircraft is afterwards flown.

A complete aeroplane or seaplane, or any of its components, calls for separate and distinct methods of treatment and these methods have now been formulated, being based chiefly on experience gained by operations of trial and error.

Not only the aircraft, but also the buildings in which it is proposed to store aircraft, must carefully comply with certain conditions, as however much care is taken with the aircraft, a badly constructed or unsuitable building may counteract all efforts to maintain the aircraft in a serviceable condition and be the cause of scrapping valuable machines.

Storage Buildings.

It is therefore necessary that buildings, unless specially designed for the purpose, should be carefully inspected and conform to certain definite principles.

These buildings should, for preference, be of substantial brick construction and be capable of excluding wet. The internal temperature should be maintained fairly evenly at about 60°F. At the same time, an installation to prevent the atmospheric humidity from becoming greater than 60 per cent. is desirable, as the moisture which is deposited when the dew point of the atmosphere is reached may easily find its way into unprotected timber and also lead to the rusting of steel parts. Particularly does excess moisture manifest itself in its action on glued joints in timber to the detriment of airscrews and built up members of aircraft; it is also detrimental to undoped fabric.

To maintain successfully a relatively constant humidity inside a large storage shed is a matter of considerable difficulty, as can be realised when it is considered that the natural humidity of the air outside the shed may vary from 20 per cent. to 100 per cent. (saturation). In winter it is easy to conceive a day when the outside air is at a temperature of say 30°F. and with a humidity of 95 per cent. Under these conditions the interior of the shed would be damp. With the air practically saturated, moisture would be deposited on the material stored and on the walls of the shed. Another possible condition which may follow a few days after that described above might be with the humidity outside the shed as low as 20 per cent. while the interior humidity may be even lower than this, caused possibly by sunshine slightly warming the air inside the shed. This would conduce to stretching of unprotected fabric and warping of timber.

So far no really successful scheme for dealing with this question has been evolved, but various devices are in use and doubtless will be improved as the importance of the question becomes more realised.

A typical modern storage shed is shown in Fig. 1, this shed being fitted with devices for the maintenance of a fairly constant atmospheric humidity.

General Principles.

Given a suitable building, each complete aircraft or its component parts must be placed so that no heavy parts are allowed to hang on weak points of the structure, and all parts must be carefully supported. Loads thrown on the centre of an unsupported span should be avoided as, with timber and in some cases with metal, such an action may produce a permanent sagging and the introduction of stresses which were not allowed for in the design of the structure.

All stored aircraft should be subjected to a periodical inspection of its various parts in order to check deterioration and to maintain it in a serviceable condition. To permit of these inspections, the methods of storage must be such as to give free access to all the principal parts, such as main planes, engines, controls, and when components are dealt with separately, to the individual items.

Many parts of aircraft are very fragile, such as the leading and trailing edges of main planes and the tail control surfaces, and these parts, when the components are stored separately, should be well protected. On the exposed surfaces of metal work a liberal supply of anti-rust composition should be applied, and the parts thus treated should not be allowed to rest against fabric parts.

Where storage space permits, and where a complete aircraft is likely to be required from storage at short notice, it is more convenient to store the aircraft in its fully erected condition so that dismantling and subsequent erection are dispensed with. It is usual, however, to release the loads on as many of the parts of the aircraft as possible, as for example, packing up of undercarriage axles to relieve tyres and shock absorbers.

If an aircraft is to be stored for a long period it is better entirely to dismantle it and to store its component parts separately, as this method permits of a more detailed inspection of the parts and ensures that most of the loads are eliminated which may otherwise produce deformation of certain members. Again, the varied construction and conditions of aeroplanes and seaplanes prevent these aircraft from receiving common treatment as regards storage.

Classification.

In dealing with the particular features and requirements of storage, it is proposed to consider firstly complete aircraft of various types and afterwards components, with typical examples of each case.

The term "complete aircraft" is understood to mean an aircraft in flying condition, containing the necessary fuel, oil and water, and in some cases other adjuncts which may be required for a particular service.

For each type of aircraft the details of these items, excluding liquid load, are laid down in part lists or schedules.

Many of the items, when once fitted, form an integral part of the aircraft, but those which do not come in this category, being usually part of the wireless and instrument equipment, may, when an aircraft is to be stored for a considerable time, be removed and stored separately.

Considering the types of aeroplanes and seaplanes separately, certain inherent difficulties become apparent with each type, but they may be classified roughly into large types and small types of aircraft and the requirements of these classifications studied separately.

For purposes of the above classification the large types are typified by the following :—

Handley Page types o/400 and V. 1500.
Vickers Vimy.
D.H. 10.
F. type flying boats.

And the small types by :—

Sopwith Snipe.
Bristol Fighter.
Avro.
D.H. 9a.
Parnall Panther.
Fairey Seaplane.
Short Seaplane.

It will thus be convenient to deal with aircraft under one or other of these headings and to consider individually the best methods for these classes.

LARGE TYPES OF AIRCRAFT.

Aeroplanes.

As a typical case of a large type and one which calls for rather special and intensive treatment, the storage methods used for a Handley Page V. 1500 aeroplane will be described. This type of aeroplane, although not now in general use, involves practically all the fundamental principles of storage which apply to all large aeroplanes. To appreciate the problem which arises in this case, the over-all dimensions of this aeroplane are given and are as follows :—

Span, wings spread...	...	...	...	126ft. 0in.
Span, wings folded ...	...	...	...	45ft. 0in.
Length, wings spread ...	...	...	...	64ft. 0in.
Length, wings folded ...	...	...	...	74ft. 3in.
Height with tail on trestles	...	...	...	22ft. 0in.
Weight ... ..	...	...	...	13.4 tons.

These dimensions indicate the size of the accommodation which must be provided, and it will be seen that a storage shed of ample proportions is necessary, especially if the aircraft is to be stored complete and with its wings spread. With regard to the height, it may be mentioned that this type of aircraft is never stored with its tail resting on the ground, so for roof clearance purposes it must be considered with its tail resting on trestles, that is, with the top longerons of the fuselage approximately level. The size of a storage shed necessary for this purpose can be seen from Figs. 1 and 2; the former showing the exterior and the latter the interior of such a shed.

It will be assumed that an aeroplane of this type has arrived by air and is to be stored as a complete machine. Neglecting for the time being the work necessary in getting the aeroplane from the aerodrome into its correct position in the storage shed, it is proposed to consider the operations which have to be carried out to meet storage requirements.

A specific sequence is given to these operations and forms a rough guide as to the order of the work. It is possible, however, that two operations may be carried out simultaneously; for instance, the instruments may be removed while the main planes are being slung.

These operations will firstly be summarised and then described in detail, and they are as follows :—

- (1) Rest tail of the aeroplane on a trestle about 9ft. high, and place two other trestles under the fuselage, one under the bomb bay and the other under the pilot's seat.
- (2) Take the weight off the undercarriage wheels by supporting each end of the undercarriage axles on special packing blocks.
- (3) With the main planes folded sling the lower planes from chains supported by standards resting on the floor of the shed.
- (4) Strap ailerons, elevators and rudders in normal position.
- (5) Drain all petrol, oil and water from tanks and systems.
- (6) Clean all the outside parts of the engine and coat these parts with vaseline or other suitable anti-rust preparation.
- (7) Remove the magnetos.

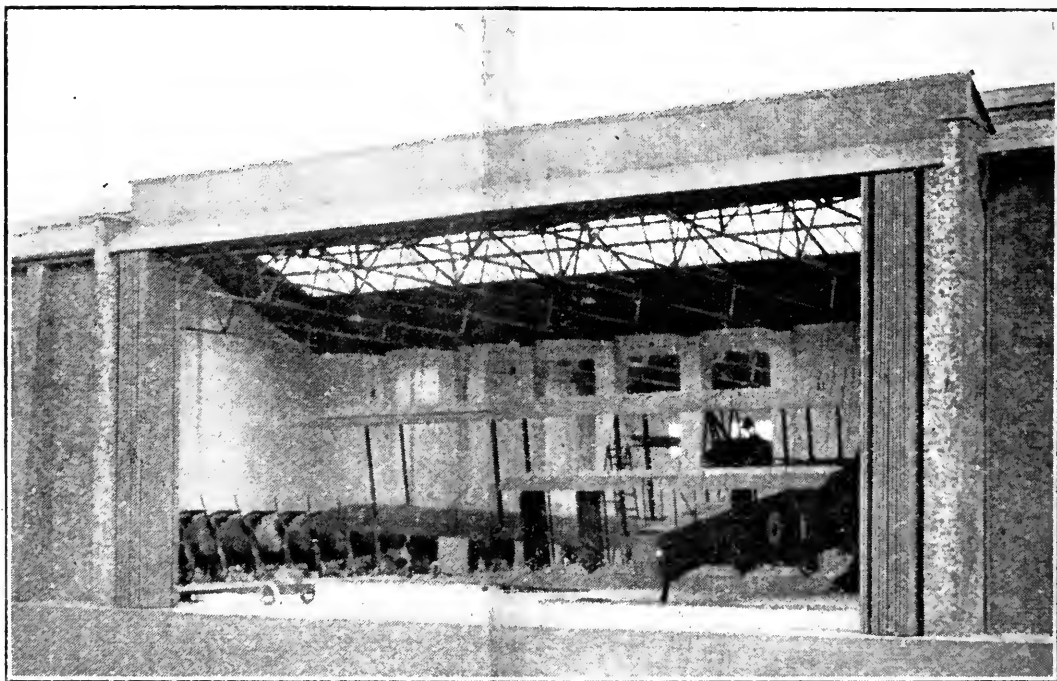


FIG. 1.—*Aircraft Storage Shed.*

- (8) Clean and grease throttle and magneto controls, especially at the hinges.
- (9) Clean engine valve springs and grease guides and stems where possible.
- (10) Dismantle and clean the carburettors, then re-assemble, closing all external apertures to prevent any ingress of grit or dust.
- (11) Cover exhaust manifold and engine breathers with fabric.
- (12) Carefully secure engine covers so that they completely enclose the engine and place drip trays under each engine to collect any oil residue.
- (13) Clean down the main planes under the engines.
- (14) Grease all control wires and pulleys.
- (15) Remove wheels and clean and grease hubs and axles, and afterwards clean each undercarriage.
- (16) Clean and grease all external bracing wires.
- (17) Wipe down the fabric surfaces.

It is proposed now to amplify the foregoing summary and to show how each of the operations may be carried out.

The main planes of the aeroplane will usually be folded before it is taken into the shed and it will have its tail resting on a transport trolley.

In the execution of operation No. 1, it is necessary to place chocks before and behind each of the wheels of the undercarriages to prevent any fore and aft

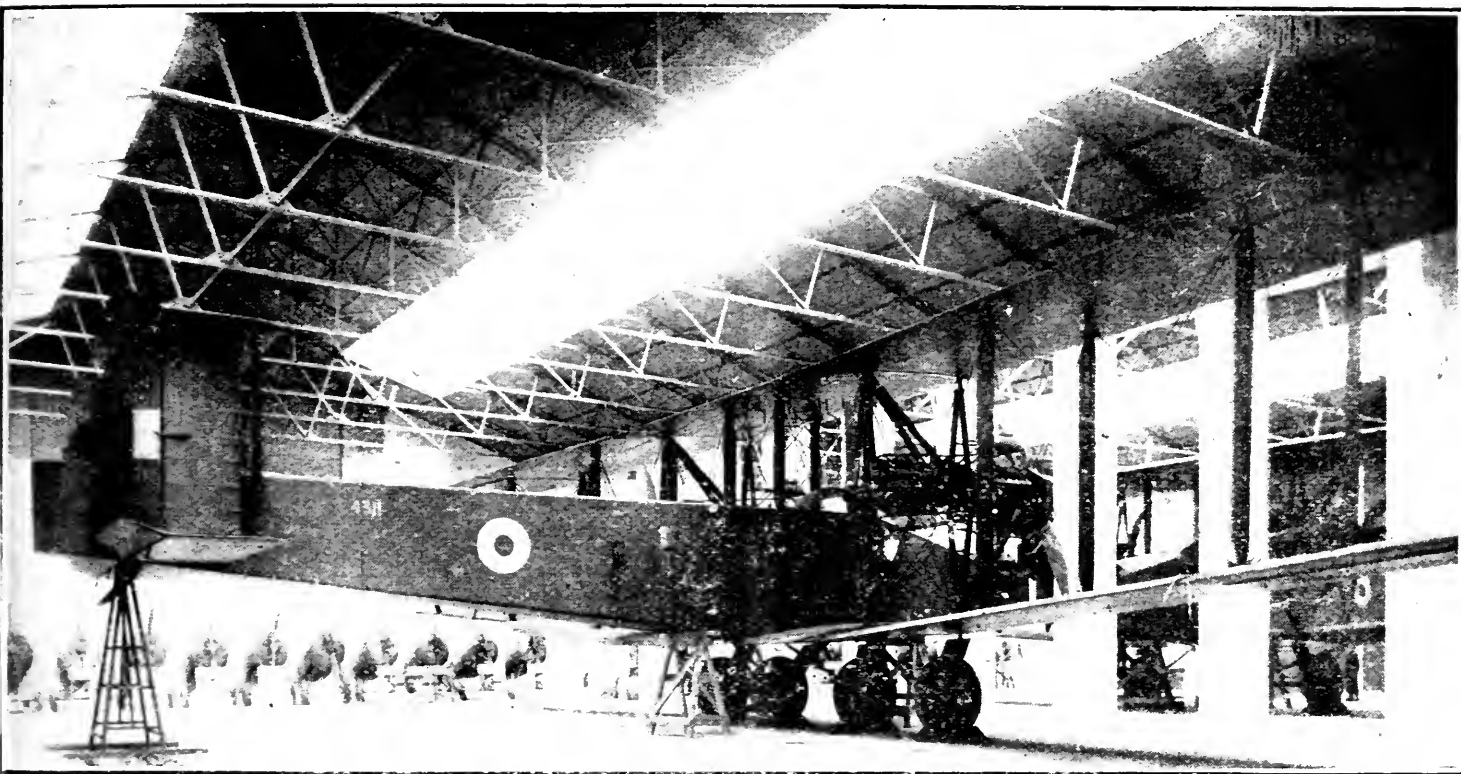


FIG. 2.—Interior of a Storage Shed.

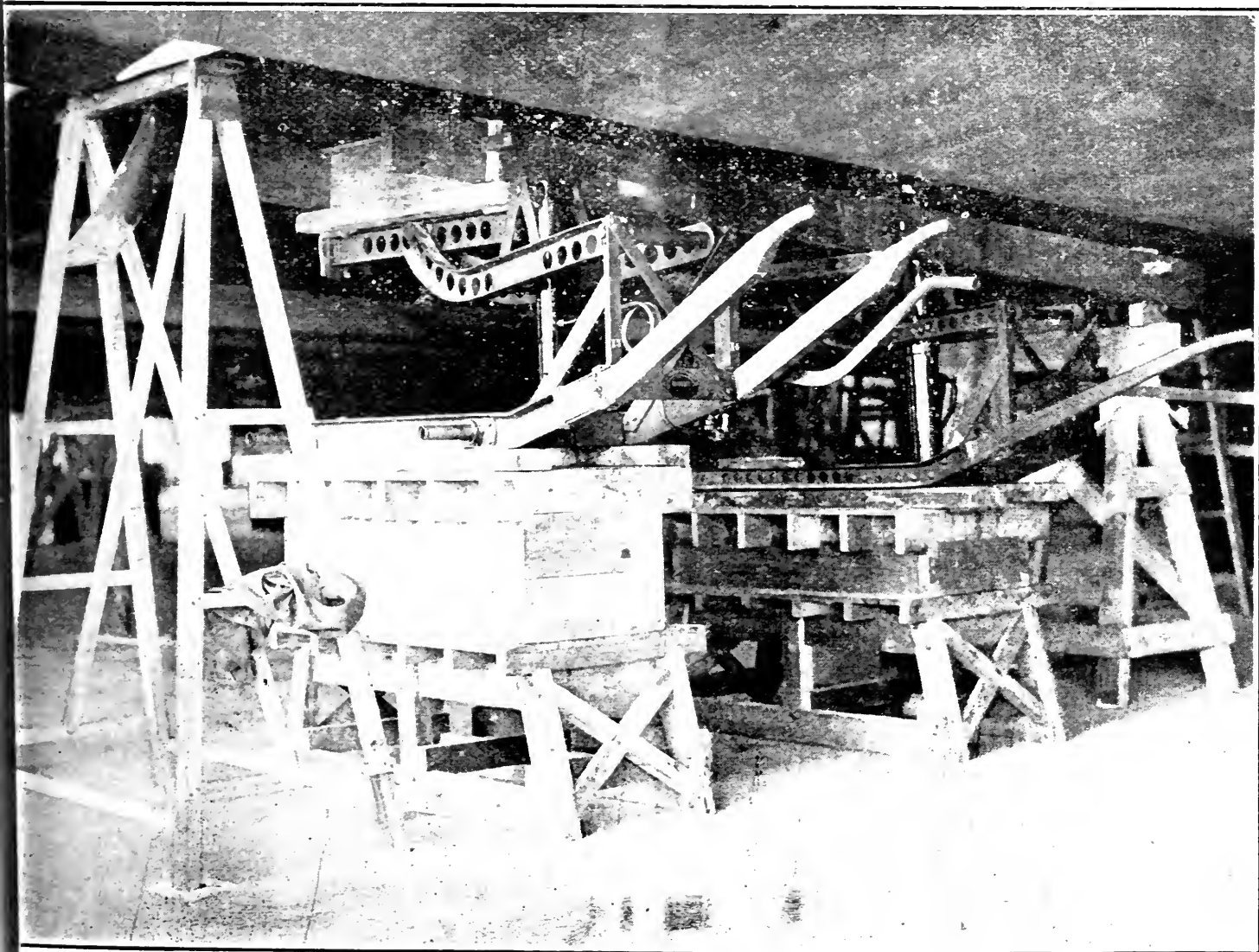


FIG. 3.—Wooden Cradle and Lifting Jacks (with wheels removed) for lifting large Fuselage.

movement of the aircraft when the tail is being lifted. Owing to the weight of this type of aeroplane, mobile hydraulic jacks are used. These jacks are wheeled under the rear portion of the fuselage and on them is laid a strong wooden cradle built up as shown in Fig. 3, the end of the cradle coming just in front of the tail skid. It is very important that the weight of the fuselage should only be taken in this manner as local loads incorrectly applied lead to distortion and possible rupture of the McGruer longerons. Operating the hydraulic jacks then raises the tail of the fuselage from the trolley, and when clear, the trolley is removed and a small trestle placed under the tail skid. When the full travel of the jacks has been completed other trestles of suitable height should be placed under the

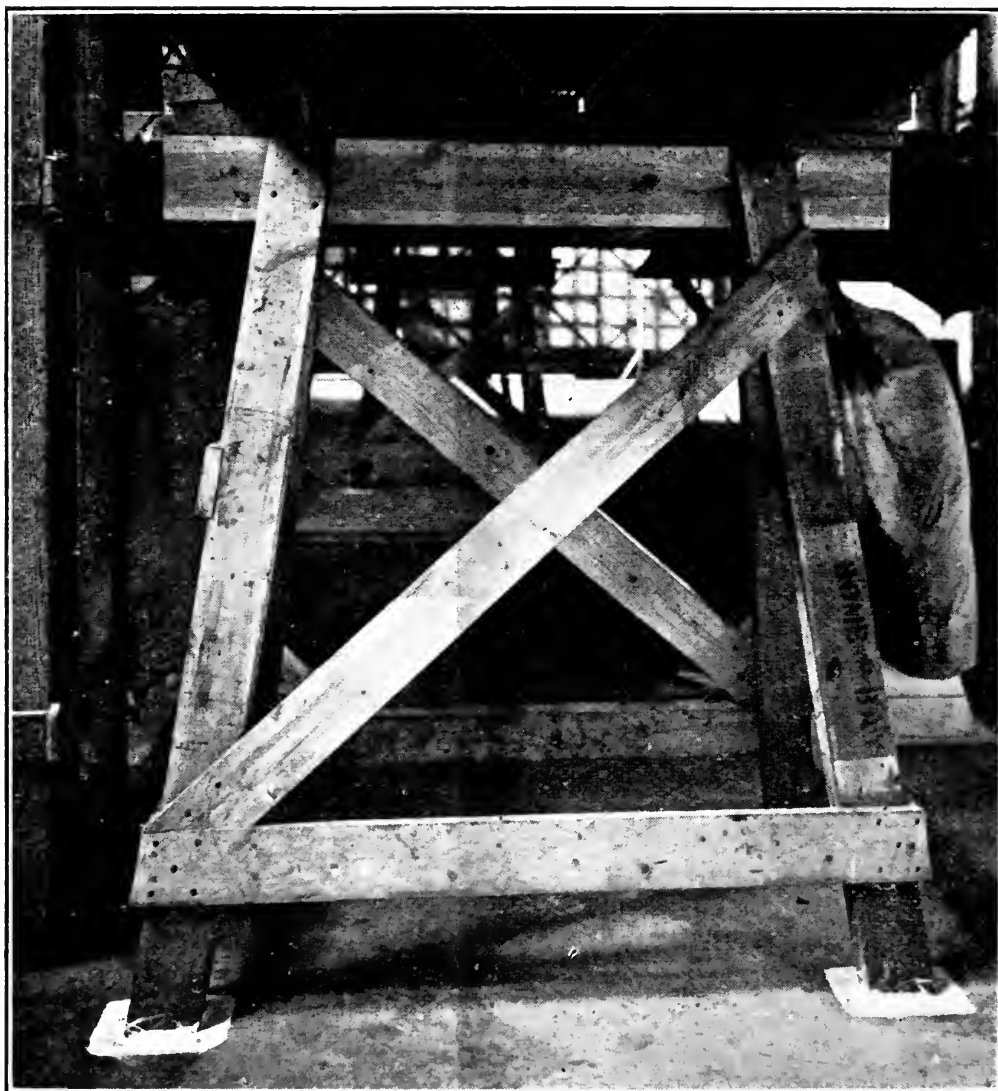


FIG. 4.—*Fuselage front Trestle.*

middle and front portions of the fuselage at the points specified by marking on the fabric. By the use of wedges and packing pieces adjustments should be made so that the weight of the fuselage is carried on the trestles, after which the load may be lowered off the jacks. Then by placing other packing supports under the jacks they may again be raised to meet the fuselage and the above operations repeated to give a further lift until the fuselage is in its correct position with the top longerons approximately level. At the points where the supporting trestles come into contact with the fuselage, it is advisable to introduce a thin packing of felt to prevent injury to the fuselage members while the weight is resting on the trestles. While the hydraulic jacks are being worked and the fuselage lifted, the supporting points on the fuselage should always be

followed up by packing on the supporting trestles to prevent damage to the longerons in the event of failure of the jacks. It must be remembered, too, that while the tail of the aeroplane is being raised the whole aircraft is pivoting about its wheel centres and as the tail goes up the front portion of the fuselage will go down. This means that as packing pieces are substituted to follow up the tail, the packing pieces under the front of the fuselage will have to be removed

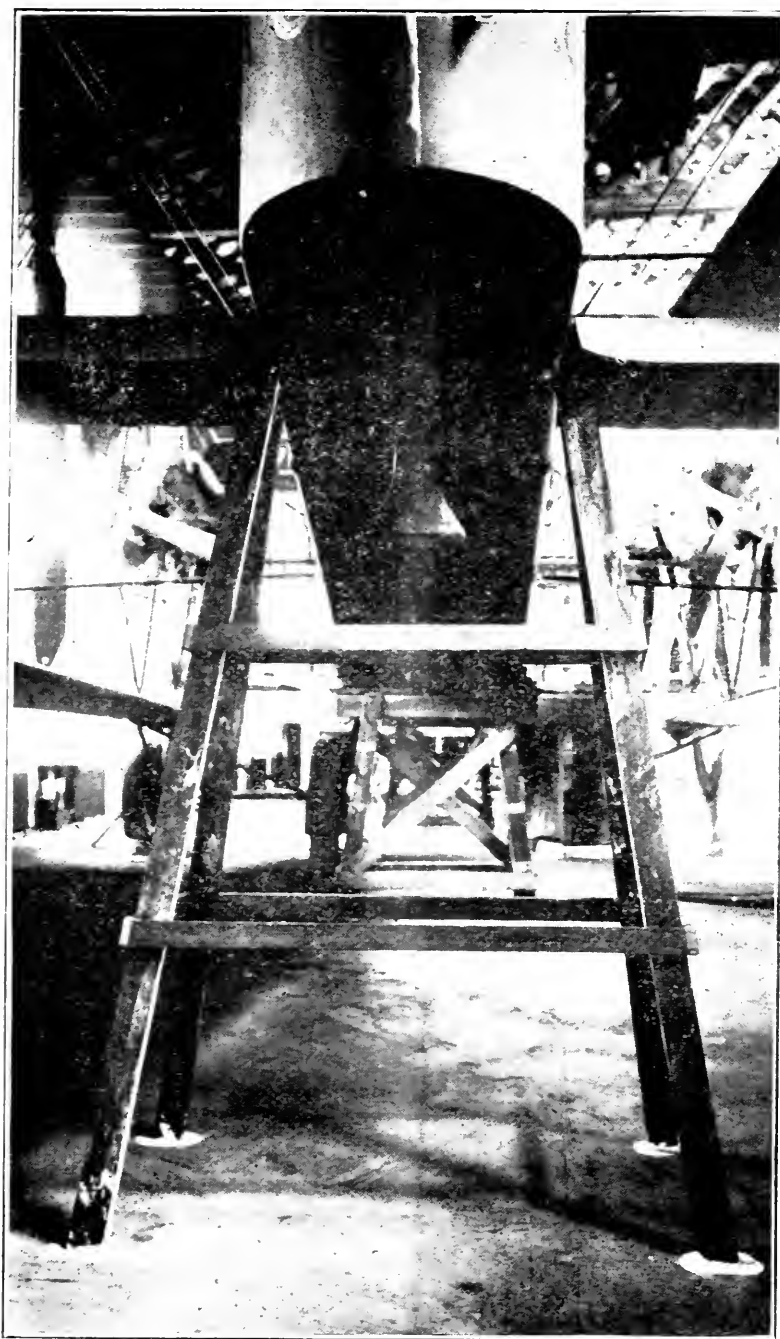


FIG. 5.—*Fuselage tail Trestle.*

and, if necessary, the trestle under the front portion taken away and a smaller one placed in position. From this also can be seen the necessity for securing the undercarriage wheels to prevent the aeroplane from rolling off the trestles. The fuselage is finally supported with its top longerons approximately level and the wedges on all the supporting trestles should be just gently tapped home until each trestle takes its appropriate share of the weight of the aeroplane. The front and tail supporting trestles in their actual positions under the aircraft are

shown in Figs. 4 and 5. In this position there will be a load of about 50lb. downwards on the tail skid, the point of balance of the aeroplane being under the bomb bay.

The next operation is No. 2 and consists of taking the load of the aircraft off the wheels of the undercarriages and so relieve the tyres of excess pressure and permit of deflation. To support the aeroplane in this position it is necessary to place packing blocks under the ends of the axles which project through the wheel hubs. It is impossible to lift by jacking the aeroplane at these points, as only about $\frac{3}{4}$ in. of projecting axle end is available and this must be supported by the packing block. Two stiff wooden beams are therefore taken and placed across the centre section lower plane as closely as possible to the tops of the undercarriage struts and each undercarriage is treated separately, the aircraft being lifted first on one side and then on the other.

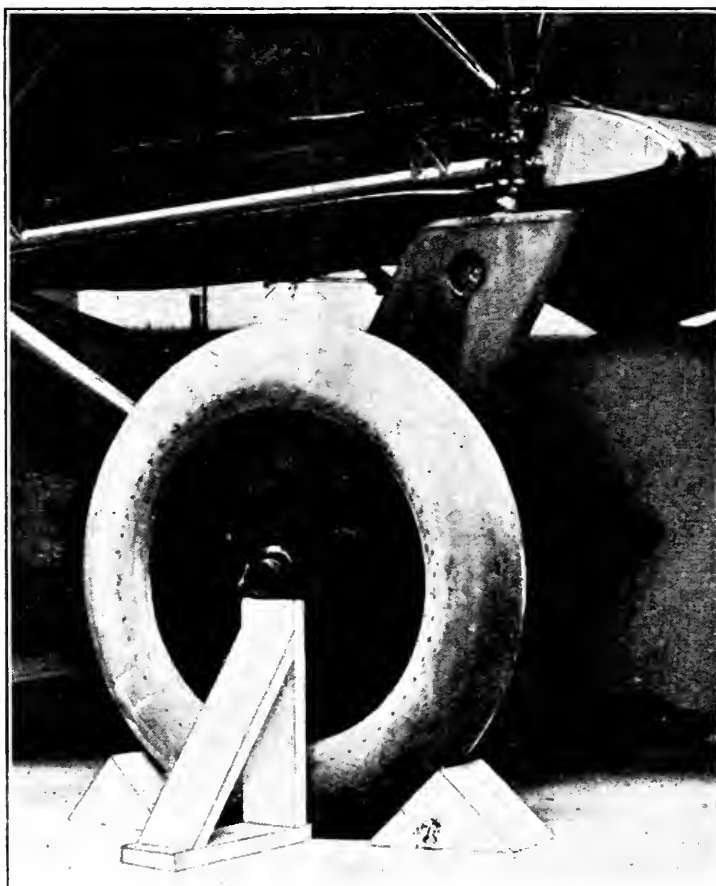


FIG. 6.—*Packing Supports for large Undercarriage.*

With the wooden cross beams in position, a hydraulic jack as used for lifting the fuselage is run under the beams and through wooden packing the weight of the aircraft is just taken by the jack. During this operation the specially constructed wooden packing blocks are placed on the floor near the ends of the undercarriage axles, and as soon as the undercarriage wheels clear the ground these packing blocks are inserted, one under each end of the axle which is being lifted. The whole machine is then gently lowered into position on these supports. The height of the packing blocks should be carefully gauged before they are placed in position and arranged so that, when in position, the wheels of the undercarriage may just clear the floor and be free to revolve. By repeating the process the other undercarriage can be supported in like manner and the complete packing for an undercarriage is shown in Fig. 6. After both undercarriages have been supported, V-shaped chocks should be placed before and behind each wheel.

It is well to note that as each undercarriage is being lifted separately, the whole machine is forced to rock slightly from one side to the other and in so doing each of the lower longerons of the fuselage have in turn to take a greater share of the weight of the machine than when the aircraft is in its normal position on the trestles. It is important, therefore, that undue lifting should be avoided during the operation. Also, supporting the undercarriages of the aircraft in this manner produces slackness in the front and intermediate fuselage trestles and makes it necessary, after the operation, to go round these trestle packings and readjust them so that they again are made to fulfil their proper functions. The small change in the level of the longerons which is occasioned by packing the undercarriage is immaterial for purposes of storage.

The aeroplane is now ready to have its main planes slung as mentioned in operation No. 3. For this purpose special standards are erected, one standard being placed in line with the lower ends of each pair of interplane struts. These standards may conveniently be constructed of wood, and they should be of such a height that they extend from the floor to about half way up the interplane struts. The load carried is not very great, but rigidity is necessary, so that

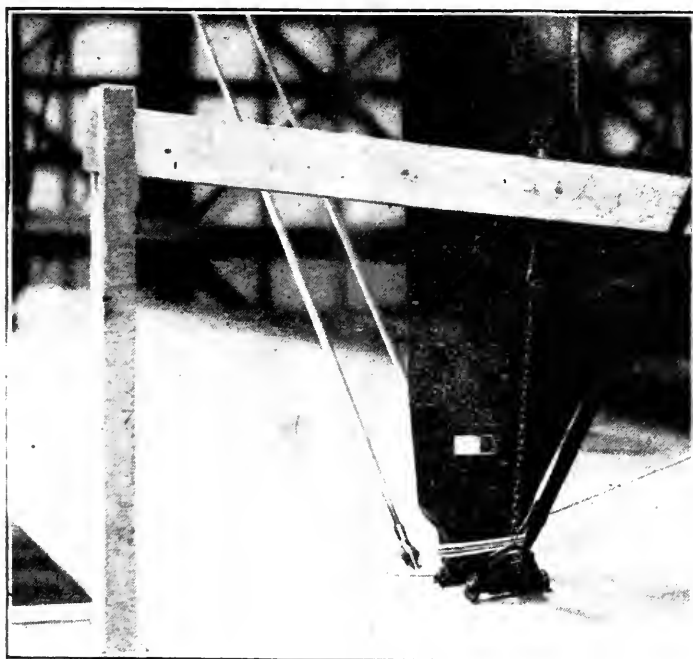


FIG. 7.—Chain Sling for Main Planes.

it is advisable to use upright members of about 3in. by 3in., and to construct the base so that the standards rest firmly on the floor. Across each pair of these standards, at their upper ends, is placed a wooden beam about 2in. by 3in., and has its ends let loosely into slots at the tops of the supporting standards so as to be easily fitted and yet unable to ride out of position when the load is placed on the cross beam. It will be found convenient to arrange the standards so that the cross beams can be adjusted to different heights for uses with aircraft of various sizes.

The weight of the main planes is carried on chain slings suspended below the cross beams, the lower ends of these slings coupling up to the bottom wiring plates of the interplane struts, and the upper end passing through the beam and having an ordinary screw attachment for vertical adjustment. The actual attachment of the lower end of the sling is shown in Fig. 7, from which it will be seen that a simple plate, bent at its end, is hooked round the anti-lift wire fitting; these plates being specially constructed to suit any particular

fitting. Two slings are attached to each cross beam and are coupled to the fittings at the lower ends of corresponding front and rear interplane struts, the amount of load carried being varied by the screw adjustment. In Fig. 8 one pair of main planes is shown thus supported.

Each sling of the pair attached to the same cross beam should be adjusted to take an equal load, as otherwise there will be a tendency to twist the main planes; also it must be remembered that by bad adjustment unequal loads are thrown on to the main plane supports. The condition to be aimed at is to have the weight of the main planes evenly distributed on each of the cross beams. By inserting springs of the same stiffness in each of the screw adjustments on the cross beams an indication of the load taken by each sling may be obtained by observing the compression of these springs, and in this way it is easier to see when each sling is taking its correct share of the load. When setting up these supporting devices the vertical standards should be placed about 4in. from

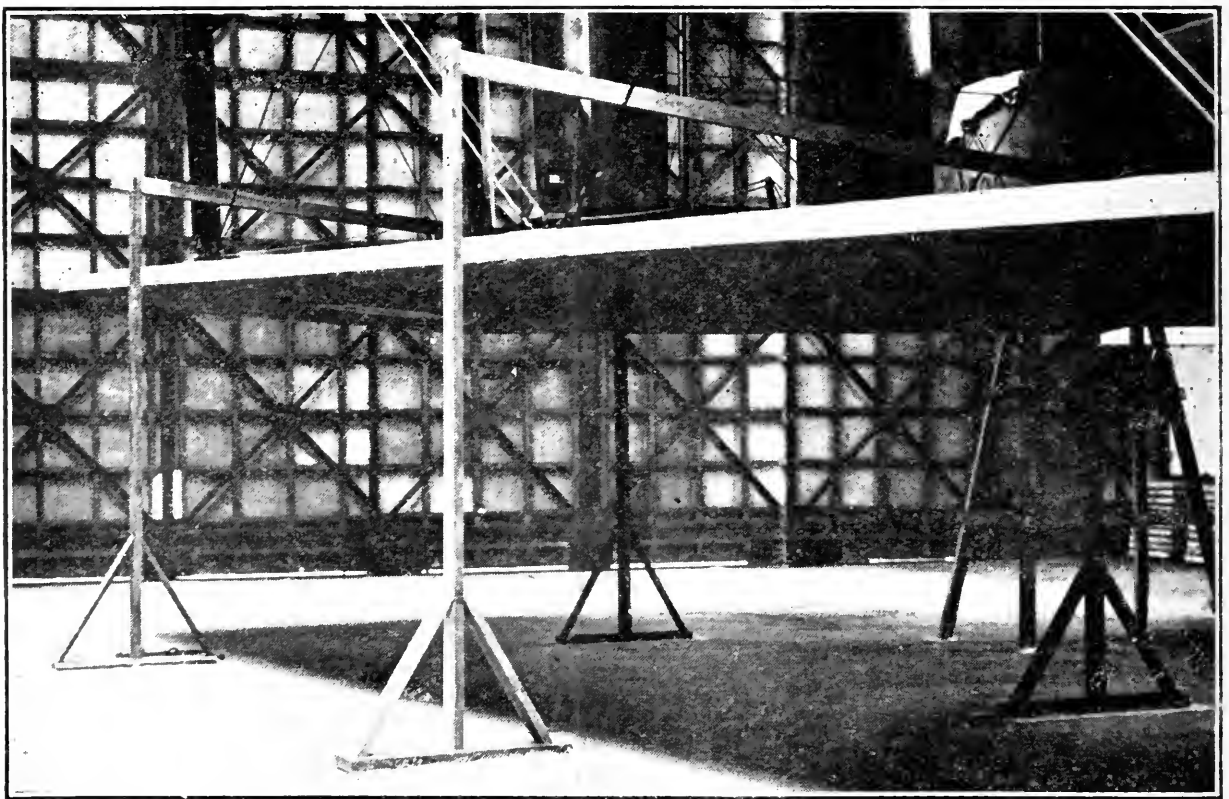


FIG. 8.—Main Plane Supports.

the leading and trailing edges of the main planes to provide allowance for possible bending of the standards when the load is taken on the cross beams, so that, if the standards happen to bend towards the wings, this clearance will prevent damage to the leading and trailing edges of the main planes. When the main planes are properly slung, the hinge joints on the centre section rear spars are relieved of a substantial amount of the weight of the planes, so that they are not so liable to be strained during storage, and the main planes are prevented from developing a permanent sag.

Operation No. 4 consists of securing the ailerons, elevators and rudders in their respective normal positions. By this means the freedom of these surfaces is limited and acts as a precaution against their being strained either by flapping in the wind, or by being forced beyond their normal limit of travel by other external means. When the aeroplane is stored with its main planes folded, the control cables from the control column to the ailerons are dis-

connected, so that the normal restraint, which could be placed upon the movement of the ailerons by locking the control column, does not appear, making the fixing of the locking devices as described below essential for holding the ailerons in their mid position. The elevators, however, remain connected to the control column, and as arrangements are made in the pilot's cockpit for locking the control column in its central position this means that the movement of the elevators is thereby limited. The attachment of a locking device to the elevators themselves is added as a further precaution against damage to the control system. For similar reasons the rudders are locked firstly on the rudder surfaces themselves and secondly through the control cables to the locked rudder bar. In most cases the control surfaces can be locked by two thin laths placed one on each side of the movable surface and clamped, handtight, to the corresponding fixed surfaces. This will give all the restraint required, but care should be taken not to damage the fabric by undue clamping.

It is next necessary, according to operation No. 5, to empty all petrol and oil tanks, and to drain the water system. In dealing with the petrol and oil, the contents of the tanks, although not to be used again for flight purposes, should be retained and used as a secondary supply. The petrol may conveniently be used for cleaning purposes or to supply ground power units, and lubricating oil, if the aircraft has not been a long time in the air, may first be filtered and then placed in store for subsequent use for ground purposes.

If castor oil has been used in the lubrication system particular care must be exercised to see that it is all thoroughly removed from the engines. This is necessary as it has been found that this kind of oil is capable of taking up moisture, and if allowed to remain stagnant for any length of time will lead to corrosion of the parts with which it is in contact. Other kinds of lubricating oil are known to retain moisture, but to a lesser extent; it may be taken, therefore, that lubricating oil should always be totally removed from the system, and particularly from the engine, before storage is commenced. In the case of water-cooled engines, the water must be drained off. When the respective systems have been emptied, the main tanks, filters and other important points may be cleaned as directed in later operations.

Considering now the operation No. 6, which directs that the engines should be cleaned down. For this purpose the outside parts of the engine are first wiped over with paraffin and petrol, the latter being conveniently some of that obtained when emptying the tanks during operation No. 5. After the removal of all dirt and loose oil the bright metal parts should be covered with a suitable anti-rust preparation. When applying these protectives in the solid state it has been found that the application, if not carefully done, may consume more grease than is really necessary, as the small spaces between the parts of the engine become filled and the open surfaces coated irregularly with an undue thickness of protective. Further, some parts may not be completely covered, thus defeating the object of the operation. It is known also that if rusting is commenced on a piece of metal, the oxidation may spread to adjacent parts, even though these parts be covered with protective preparation. To overcome these drawbacks, the anti-rust preparation should first be melted down so that it can be applied to the parts of the engine with a brush. This method leads to a much more efficient distribution of the grease, and the whole operation may be carried out in far less time than when the grease is applied in its solid state. When melting the grease only just sufficient heat should be used to make it run freely, as excessive heating may change the properties of the grease and render it less efficient as an anti-rust protective.

For this and other operations on the engines of large aircraft, a special scaffolding may be erected, which enables the men to obtain access to all parts

of the engine and to work in a convenient position. A general view of such a scaffolding may be seen in Fig. 9, and any similar erection may be used.

The next operation, No. 7, provides for the removal of the magnetos. These important parts are susceptible to the effects of moisture and require to be kept dry. After removal from the engine, the magnetos are usually labelled to associate them with a particular engine and then cleaned and stored in a manner to be described later.

Continuing with the engines and passing to operation No. 8, the throttle and magneto control should be cleaned and greased so as to ensure that they

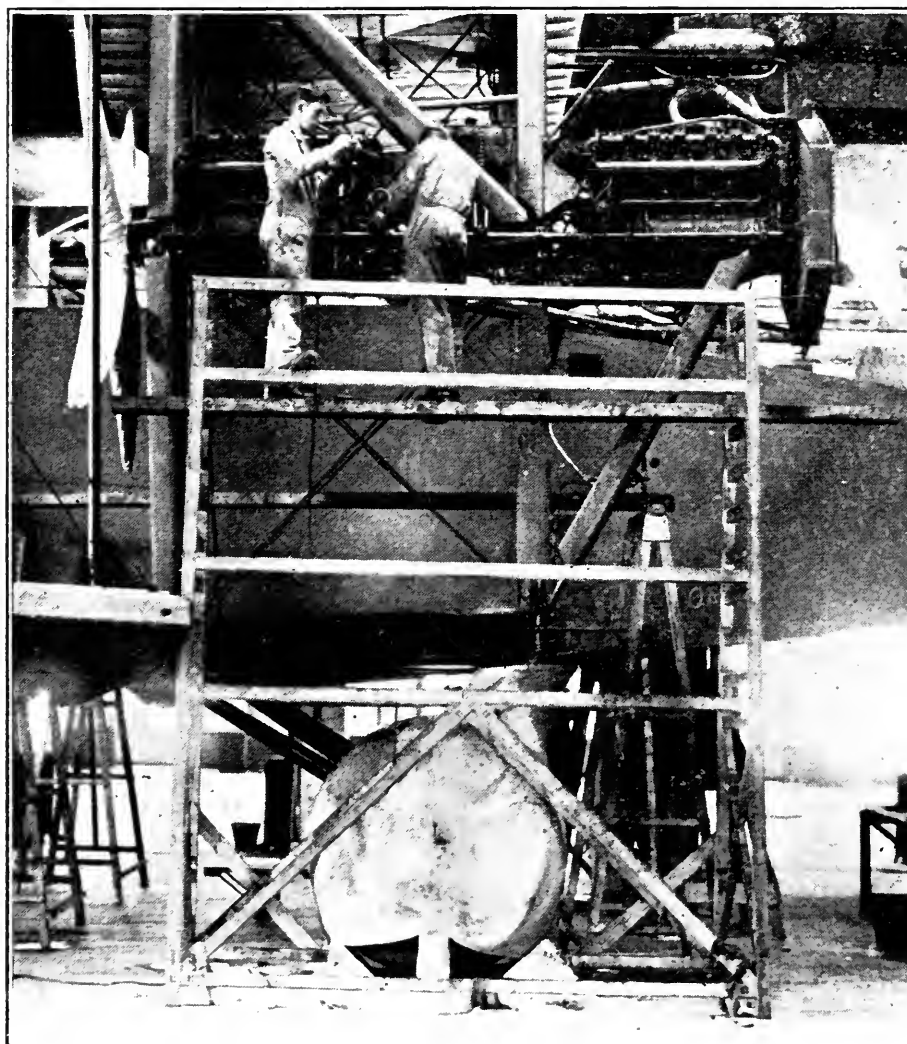


FIG. 9.—*Engine Scaffolding.*

will work smoothly. In the type of aeroplane under consideration, these controls are built up of hinged rods and are positive controls; the system necessarily contains a number of hinged joints which connect various portions of the rods, and these joints should be lubricated and overhauled for possible defects.

Next overhaul the engine valve gear, at the same time cleaning the springs and greasing the valve guides and stems where possible. The engine is not dismantled for this operation, which must be considered to apply to the external portions only. In this case the protective grease may better be applied in the solid state.

Proceeding to operation No. 10, the carburettors should then be dismantled and cleaned. For this purpose they are first taken off the engine, and while the cleaning is in progress the apertures leading to the induction system should

be closed either by a fabric covering being placed over the holes, or by lightly plugging the induction apertures. In this way dirt may be prevented from getting into the engine, and while the carburettors are removed, the induction apertures should not be uncovered for any other operations which are being carried out on the engine.

After the carburettors have been cleaned and are re-assembled, they should be replaced in their position on the engine; at the same time control rods should be connected up and the whole system tested through to see that it is working satisfactorily. This operation practically completes all that is required on the engines, and it remains now to ensure that, having once cleaned the engine down, no dirt or other undesirable matter can enter and so cause a repetition of the work.

Operation No. 11 is designed to this end, and it entails covering the exhaust manifold and engine breathers to exclude dirt. For this purpose it is customary to use fabric which, when cut to suitable use, may be secured in position by either wire or balloon cord. It is common practice to remove all the plugs from the cylinders, and when this is done the plug holes should be filled temporarily with close fitting pieces of wood.

Before leaving the engine operation No. 12 should be carried out and the engine covered completely by a large piece of fabric specially shaped for this purpose, a pair of engines with these covers in position being shown in Fig. 10. Covers of a similar material are also made and placed over each of the blades of the airscrews.

Although the engines have been previously drained there is usually a small quantity of oil which remains and finally drips from the engine. To prevent this oil from falling on to other parts of the aircraft, fabric or metal drip trays are hung one under each engine. These trays may be slung in any convenient manner and should extend along the whole length of the engine.

The next operation, No. 13, calls for the cleaning of the main planes under the engines. While the engines are running a certain quantity of oil oozes out and finally collects under the crankcase and drops on to the fabric of the main planes. With a well varnished dope no injurious effects can occur, but the protective coating on the fabric cannot always be relied upon to resist the oil, and troublesome results may occur if the dope film fabric is cracked or has been incorrectly applied. This oil may be cleaned off as described later; no hard rubbing or scraping of the fabric is desirable or necessary, as it is required only to remove the surplus oil and dirt, and care must be taken not to damage the dope film or the surface of the fabric.

The controls and controlling surfaces of the aircraft should next receive attention under operation No. 14. The control cables to the ailerons are necessarily disconnected when the aeroplane is folded, but the control cables for the other surfaces remain intact. In each case a cable run from the pilot's control wheel should be followed through to its respective controlling surface, and where these cables pass over pulleys or through fairleads a careful inspection should be made for cable fraying or other weaknesses; it is unusual for a cable to develop weakness at other points. If any cable is found to be inefficient, it should be plainly marked so that it may be replaced before the aeroplane is next taken into the air. All pulleys and fairleads should be greased, quick release fittings, if such are fitted to the cables, should be tried and cable splices wiped over and inspected.

Continuing to operation No. 15, this directs the removal of the wheels and the cleaning of the hubs and axles. It will be remembered that operation No. 2 arranged for the wheels to be lifted from the ground and to be held in that position by specially constructed packing pieces under the ends of the axles; before the wheels can be removed, therefore, it will be necessary to find another

temporary point of support for the undercarriage, so that the outside packing blocks may be removed and the wheels drawn off the axles. This provisional packing for the undercarriage may conveniently be placed under the axle and immediately behind each wheel, and the load taken off the outer packing pieces by jacking the undercarriage through wooden beams placed across the lower centre section as near as possible to the tops of the undercarriage struts. In this way the load may just be removed from the outside packing and lowered again on to the packing on the inside of the wheel. This enables the wheel to clear the ground, and after the removal of the retaining pin at the end of the axle, it may be withdrawn. When removed, the wheel may be cleaned down and the air pressure in the tyre reduced to prevent fatigue of the rubber. The axle end may be cleaned and coated with a fresh supply of grease lubricant. The wheel is then replaced on the axle and the load again taken by the jack, so that the provisional packing may be removed and the packing bracket inserted under the axle end. This operation is then repeated on each wheel in turn. If a faulty tyre appears, it will be found convenient during this operation to provide a replacement from store. When the work on both undercarriages has been finished, each wheel and spring shock absorber should be protected by a suitable waterproof cover, as shown in Fig. 10, which may be fastened round the top of the shock absorber and arranged so that it completely covers the whole unit.

The next operation is No. 16, and entails the cleaning of all external bracing wires and cables. In this operation, it is not essential that streamline wires be polished, although this is sometimes done, but in any case, after the wires have been cleaned they should be covered with an anti-rust preparation. It is advisable also to apply this protective to cables where such occur. In the case of streamline wires, these may conveniently be cleaned by rubbing parallel to their length so as to avoid their being twisted. This operation also affords an opportunity for the examination of turnbuckles and locking devices, and to see that all these are securely attached, with the exception, of course, of bracings containing quick release fittings.

When working on aeroplanes of the size under consideration it is not possible to reach the top of the main plane bracing wires without the aid of a scaffolding. With the main planes folded and supported as described in operation No. 3 no extra weight must be placed upon them, and to give the desired access to the main plane bracing wires the scaffolding should consist of planking placed across and between the main planes, being supported on trestles of suitable height. By adjusting this platform to various heights the whole of the bracing wires can be reached. To deal with the bracing of the tail planes, another similar scaffolding is erected against these surfaces.

Some of the internal bracing wires of the aircraft may also be cleaned as they are accessible, but in normal usage they are not exposed to the weather, so that it is only necessary to give a superficial treatment. The internal bracing wires of the fuselage are the principal ones which fall into this category, and in passing down inside the fuselage to carry out the work, care should be taken not to damage the fabric or cross struts. The operation may be facilitated by placing light boards along the tops of the bottom cross struts and by working from these boards.

Operation No. 17 completes the work necessary for storage of the complete aircraft, and directs that all fabric surfaces should be cleaned down. It will be found that some parts of the fabric become splashed with oil, especially near the engines, and others, such as the under surfaces of the lower main planes, may be coated with mud. The removal of oil from doped fabric has already been mentioned, but it remains to be added that the effect of oil is to increase the weight of the plane and to cause slight slackening of the fabric. On the type of oil used will depend the method used for its removal. In the case of vacuum

oil, this should be treated with soft soap and water and afterwards wiped down with benzol. With castor oil, which has a tendency to penetrate through the varnish and dope, the removal is more difficult; it can, however, be treated successfully by the use of soap and water, provided this treatment is applied before penetration of the oil to the fabric has had time to develop. Other cleaning agents such as petrol and alcohol may be used, and in the absence of benzol, petrol may be substituted. The soap and water dressing may conveniently be applied with a soft brush, and the other liquids with a pad of cotton waste wrapped in calico. It should be remembered that the action of petrol during cleaning is to remove the varnish from the dope film so that after such an operation the film is exposed and liable to crack and to lose its waterproof qualities. The petrol should therefore be used sparingly and only applied to the parts immediately concerned.

In the removal of the mud which may be thrown on to lower main planes by the wheels, it is not advisable to use any rubbing action, especially if the mud has had time to solidify. Rubbing this dirt under these conditions would lead to a considerable injury to the dope film and destroy all its protective qualities. As a preliminary treatment, therefore, the removal should first be effected by a water jet, and when most of the mud has been washed away, the small amount remaining will be so softened that washing with soap and water may be carried out without injury to the plane. It is obvious that continual cleaning by any liquids of one part of the fabric will eventually lead to the destruction of the dope film, and in places where the dope is found to be cracked by previous cleaning processes, these parts should be carefully treated so as not to aggravate the trouble, thereby allowing oil and water direct access to the bare fabric. Parts of the aircraft which do not suffer from the effects of oil or mud may be just lightly wiped over for the removal of dust or water. The operation of cleaning the whole aircraft affords an opportunity for the detection of such internal defects as a damaged rib or trailing edge.

The foregoing 21 operations may be taken as representing roughly the complete sequence which is required for the storage of a large type of aeroplane, such as is shown in Fig. 10. For obvious reasons this cannot be applied to every type of aircraft indiscriminately, but the fundamental principles will remain the same, modification being introduced to suit any given set of conditions.

Where shed spaces permit and when it is probable that the aircraft will not be in store for a long time, it will be found an advantage to store the complete aeroplane with its wings spread. From a point of view of storage space this is, of course, not so efficient a method as with the wings folded, but it is convenient when the aircraft has to be placed in commission on short notice. A typical illustration of an aeroplane thus stored is given in Fig. 2, which shows that the fuselage is supported on trestles with its top longerons horizontal as before. The undercarriages are lifted and supported with their wheels just clear of the ground, and fore and aft packing blocks placed in position. The main planes under these conditions require no additional supports, and their weight is taken up by the anti-lift bracing wires. These conditions of short duration storage do not call for the removal of the instruments, and in a properly constructed shed the engines need not be covered.

Seaplanes.

In the case of a large boat or float seaplane much of the detail for storage will remain the same as for an aeroplane, with, of course, special treatment added for the hull of a boat seaplane.

As outlined previously, a seaplane falling into the classification of a large type, may be taken typically as the "F" type flying boat. The size of this

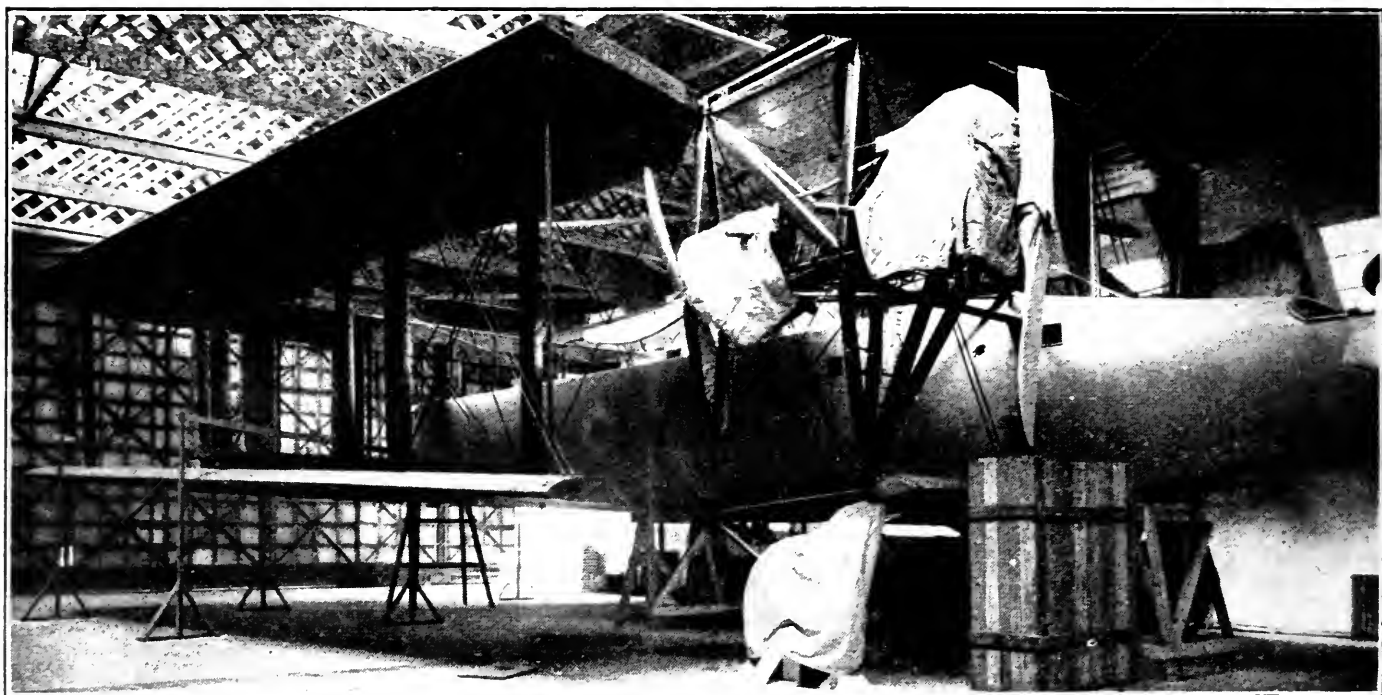


FIG. 10.—A large Aeroplane in Store.

type of aircraft is approximately, height 17ft. 6in., span 95ft. 8in., and overall length 46ft. 3in.

Assuming the seaplane is placed in its correct position in the storage shed, the shape of the hull does not permit of its being lowered directly on to the floor, but it should be accommodated in a strong wooden cradle built to fit its under side. In this way the weight of the machine is distributed and damage to the hull avoided. For prolonged storage the aircraft is therefore transferred from its transporting or beach trolley to the storage cradle, while for shorter periods of storage it may remain on its trolley. A boat seaplane supported on its trolley is shown in Fig. 11, this position being equivalent to that of the large

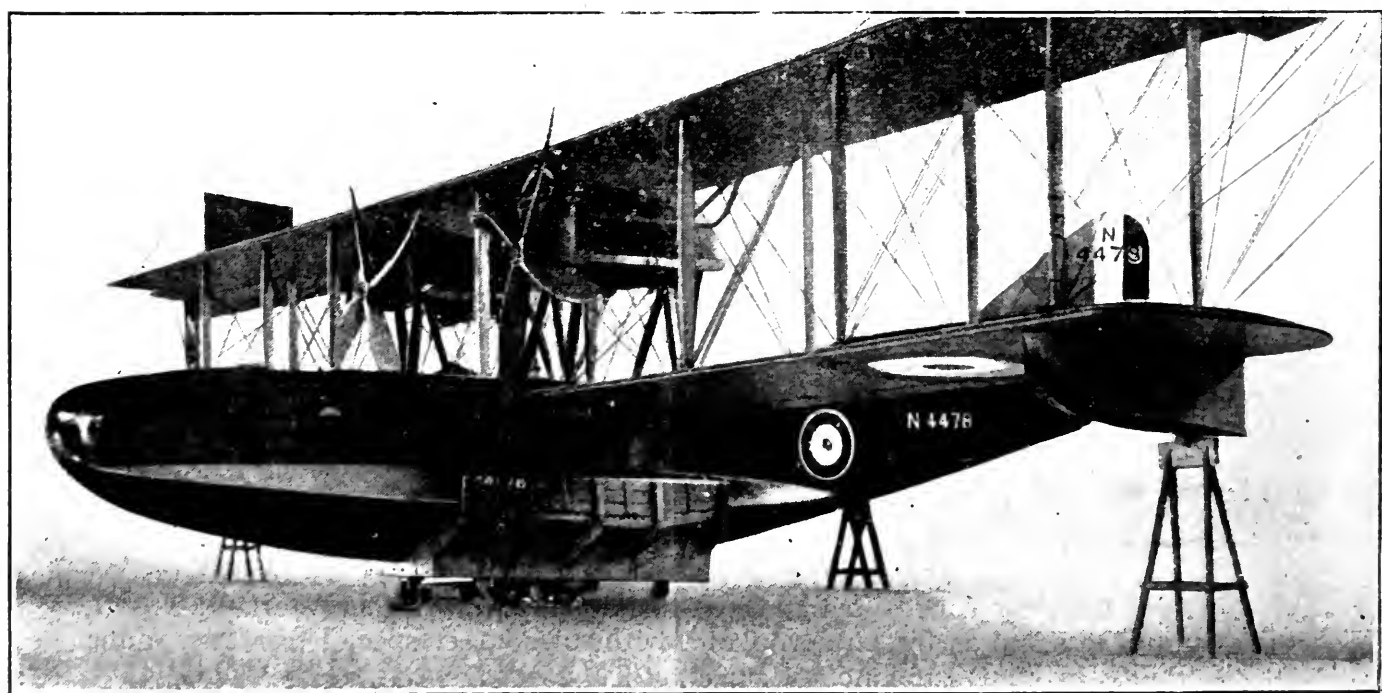


FIG. 11.—A large Boat Seaplane in Store.

aeroplane with its fuselage on the supporting trestles. The variation in the treatment for storage of a seaplane as compared with an aeroplane is chiefly in the operations on the hull.

With a seaplane taken directly from the water and placed in the storage shed, it is firstly necessary to remove all surplus water from the hull and to wipe over the entire hull structure.

With the hull resting in its cradle on the floor of the shed, the weight of the main planes can be taken up in a manner similar to that employed for a large aeroplane, that is, either by placing trestles in convenient positions near the wing tips and packing up under the wing tip floats or by placing standards in line with the interplane struts and slinging the bottom planes. When the former is done care should be taken to place the trestles only under the keel of the floats. With the hull resting firmly in its cradle, the main planes will take up a definite attitude, and in taking the weight of the main planes care should be exercised not to over-pack on the trestle supports, which not only will tend to rock the hull in its cradle, but also will subject the main planes to stresses equally bad as though they were unsupported. With the whole aircraft thus supported, the various operations prior to storage may proceed, and will consist in the main of those detailed for a large type of aeroplane. It is, therefore, unnecessary to reiterate this detail.

The most important feature is the cleaning down of the hull and superstructure, including the external bracing wires. Sea water has a very actively corrosive effect upon steel and other metals, so that the necessity for removing all surplus water is accentuated. The tendency of modern practice is to provide permanent protection of the external bracing wires and other exposed metal parts by treating them before they are embodied in the machine. Galvanising of steel parts forms a protection against the corrosive effects of sea water, but even when this is done, it is necessary to remove all water which may have collected on the parts thus treated. For similar reasons the aluminium fittings are sometimes treated with a special type of varnish consisting of one part of velure varnish and two parts of turpentine. In cases where such treatment has not been given to the metal parts, such as uncovered steel struts, the removal of surplus water should be followed by a liberal application of mineral jelly. The conditions of the hull of being alternately wet and dry are detrimental to its efficient storage, and for this purpose provision should be made to keep the hull watertight. Various methods of doing this are possible, one being the application of damp matting to the hull structure. This matting should be redamped as frequently as may be necessary, having regard to the local conditions of the atmosphere, and should not be placed near metal parts, but only over the wooden parts of the hull which normally come in contact with the water. Shrinking of the hull structure is thereby avoided, and the joints maintained watertight. A further method will be described later, when dealing with hulls as components.

The wing tip floats being of three-ply construction and their functions also producing alternate wet and dry conditions, similar treatment should be given as for hulls. For prolonged storage the floats may be removed from the main planes, and in this case they will be dealt with as separate components as described later. If they remain on the seaplane during storage they should be maintained externally damp to prevent the joints from opening.

The main fabric surfaces should be cleaned down and oil which may have dripped from the engine removed as described previously.

The detail required for the engines follows on the same lines as for an aeroplane, but having regard to the possibility of sea water entering the engine parts, particular care is necessary in cleaning down these parts, and the following application of mineral jelly should be made as thorough as possible.

Air screws are protected in the usual way, by enclosing their blades in fabric bags which are connected together at the boss of the airscrew, the blades having previously been wiped over.

SMALL TYPES OF AIRCRAFT.

In passing to the storage of small aircraft a new set of conditions are encountered, and it does not follow that the whole of the operations described for the storage of large aircraft may be produced as it were in miniature and applied to smaller machines. However, many of the general principles remain the same, but it should be remembered that although the weights of the parts of these aircraft may themselves be much smaller, yet the much lighter construction which goes with it combines to produce similar stresses in the parts and indiscriminate storage may produce considerable depreciation and inefficiency.

As in previous cases, the methods of storage have been demonstrated by the considerations of an actual type of aeroplane and seaplane, so in this case the procedure will be associated with definite representative types of aircraft which fall into this category.

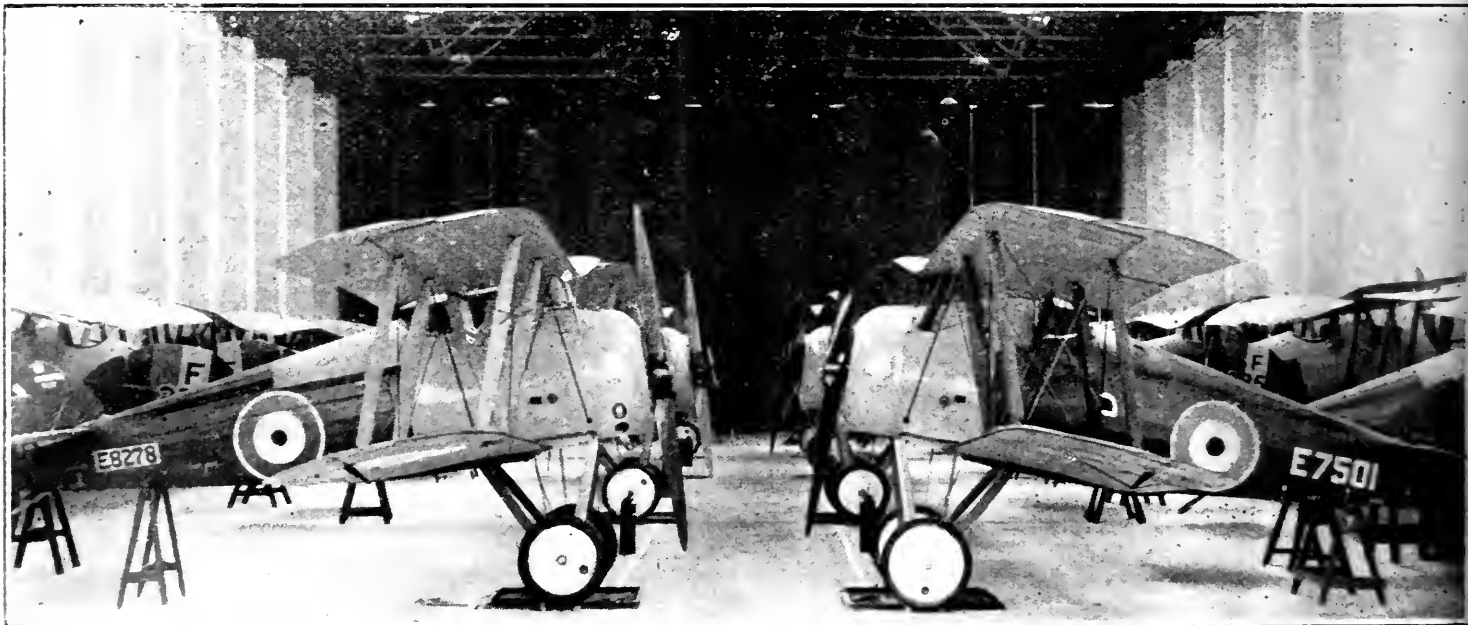


FIG. 12.—*Small Aeroplanes in Store.*

Aeroplanes.

To deal firstly with an aeroplane, it is proposed to take as an example the Sopwith Snipe, which has a span of 31ft. 1in., an overall length of 19ft. 10in., and a height with the fuselage on trestles of 8ft. 9in. It is fitted with a 200 h.p. B.R.2 engine, and is a single seater aeroplane.

It is not usual to construct special storage sheds for each type of aircraft, so that the buildings have to be adapted to house either large or small types of aircraft. Again there is usually a greater number of small aircraft than large ones in use, so that when housing the smaller types regard must be had to efficiency of accommodation, and simply because a storage shed is comparatively large is no reason for the inefficient use of floor space.

Considering now the storage of Sopwith Snipe aeroplanes. Firstly, as complete aircraft, they should be carefully arranged in the shed, and then each aeroplane should be supported in the manner about to be described. One such arrangement is indicated in Fig. 12, but this must not be taken as the only

scheme which may be used. When the aeroplane has been placed in its appointed position, the tail should be raised so that the intermediate supporting point of the fuselage, as marked by an arrow, rests on a trestle about 30 in. high. The undercarriage is now supported by packing blocks placed under the axle just behind each wheel and so that the wheels are clear of the ground. To collect any oil which may fall from the engine a drip tray containing sand should be placed between the wheels and under the engine. These operations complete all that is necessary for the actual supporting of the aeroplane; it then remains to go over the machine and perform similar operations to those described in Nos. 5, 6, 8, 9, 10, 14, 15, 16, and 17 relating to the storage of large aircraft.

The parts of a small aircraft are more accessible than those of large types, and with the exception of the upper main planes, most parts of the aircraft can be reached from the ground.

After cleaning down the whole aircraft the air pressure should be released from the tyres. The engine should next receive attention, and be cleaned externally, with a final coating of an anti-rust preparation on all outside parts. It will be found convenient to apply this protective in the liquid state as described previously. As in this type of aircraft a metal cowling is arranged to cover the engine, the protection afforded by this means is usually relied upon for the exclusion of dirt when the aircraft is stored, but in order to supplement the cowling and for use during prolonged storage, an additional covering of waterproofed fabric should be placed over the front of the aircraft so as to cover entirely the cowling in the engine. This cover should be drawn up tightly round the propeller boss and laced closely under the engine.

In an alternative method of storage of a small aircraft, partial dismantling is resorted to. The aircraft under these conditions is usually dismantled into the fuselage complete with undercarriage, engine, airscrew, fin and rudder, the main planes, the tail plane, and the elevators. With this method only a small amount of work is required to re-erect the machine if it is required from store on short notice. Both this and the former method of storage, however, are not used for the periods of storage longer than approximately two months; greater periods than this call for complete dismantling of the aircraft. When erected, the wings of any aircraft are necessarily parts which occupy a large portion of shed space, and their removal for separate storage allows a greater number of aircraft to be stored in a shed of a given size.

For storage in the partly dismantled condition, the metal parts of the aircraft are all cleaned and greased before dismantling. Covers are then attached as required, usually over the engine and over the pilot's cockpit, the latter not being necessary when storing aircraft complete, owing to the short duration of storage. It is well that the main planes and tail plane, although removed from the fuselage, should be associated with their particular machine by storage references, which may be done either by written records with a system of numbering, or, as will be described later, by grouping them with the other adjuncts of the aircraft of which they are part. Reference to Fig. 13 will indicate one method by which partly dismantled aeroplanes may be stored, and shows the complete fuselages with their undercarriages, engines, fins and rudders fitted, and supported with their wheels off the ground. Each centre section plane rests against its respective fuselage. In this case, some of the weight having been removed, it is not found necessary to raise the rear end of the fuselage on to a trestle, and it is consequently seen resting with its tail skid on the ground. In passing it may be mentioned that the airscrews have from time to time to be turned to different positions, and this should be remembered when attaching the covering over the engine.

The storage of the main planes and tail planes of these aeroplanes will be described later.

The other method of storage, in which the components of each aircraft are grouped together, will now be considered. The scheme has been devised for compactness of storage and to avoid a number of clerical cross references for identification of the parts of an aircraft.

The aircraft is accordingly dismantled to the extent of removing the main planes and tail unit, leaving the fuselage fitted with undercarriage and engine. The whole components of one aircraft are then placed together, in as compact a form as possible, in the storage shed, the general arrangement of such a scheme for the Parnall Panther being shown in Fig. 14. In planning out aircraft under this arrangement, the fuselage is first placed in position in the shed and has the wheels of its undercarriage supported just clear of the floor as in former cases, and its tail skid resting on the floor. The other components of the aircraft are then packed round the fuselage, which may conveniently be done by placing all

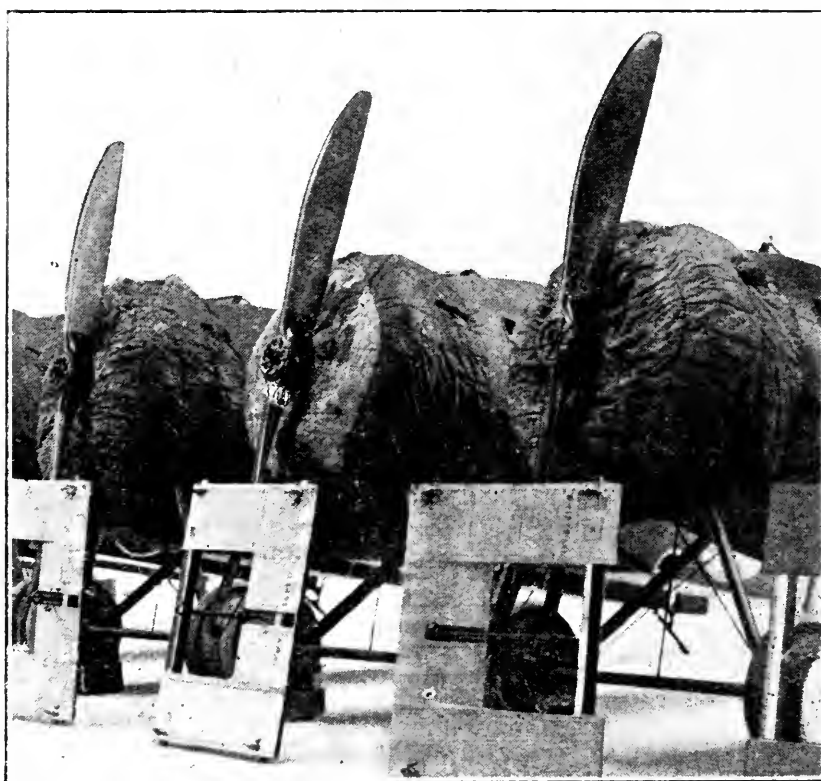


FIG. 13.—Storage of small Aeroplanes partly dismantled.

the interplane struts and wires on the floor under the fuselage, the centre section plane in front of the fuselage, the tail plane and elevators at the side of the fuselage near the tail end, the main planes in pairs down the respective sides of the fuselage and all other loose equipment in the cockpits. The airscrews for machines so stored are usually removed and stored separately. A detail view of D.H.9 aeroplanes stored in this way is shown in Fig. 15.

In storing aircraft in this manner there is a considerable possibility of damage being done if care is not exercised in the way the components are placed together, and it can be seen from Figs. 14 and 15 that the main planes and other fabric surfaces are the most liable to damage. Taking the case of the main planes, these can simply be left lying loosely against the fuselage, or alternatively they may be first fixed in cradles as shown in Fig. 15. Where possible also the leading edges should be protected, and if the main planes are accommodated in the cradles this protection is given, otherwise at certain points along the leading edges felt pads should be placed to carry the planes, and thereby raise them from the ground throughout their entire length. In

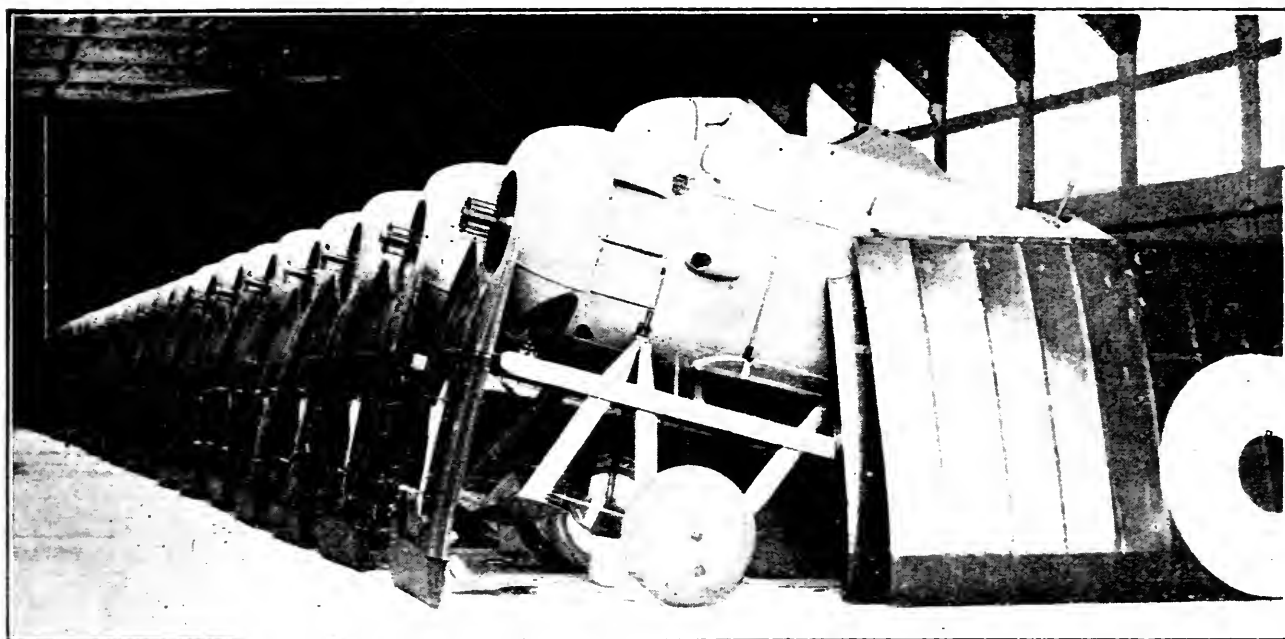


FIG. 14.—*Collective Storage of Parnall Panther.*

placing the main planes against the sides of the fuselage care should be taken to see that there is no prominent projection such as the lower centre section end rib, or other like fitting which may damage the planes; the weight of the planes is not great, but to rest them even lightly against the fuselage, so that they were bearing on one point of the fabric only, would probably involve injury to the plane. Again, it should be remembered that unless the main planes are supported throughout their entire length they will, after a time, be liable to permanent twist by the drooping of the unsupported portion. For these reasons, therefore, it is better to fix the main planes in a suitable frame and to

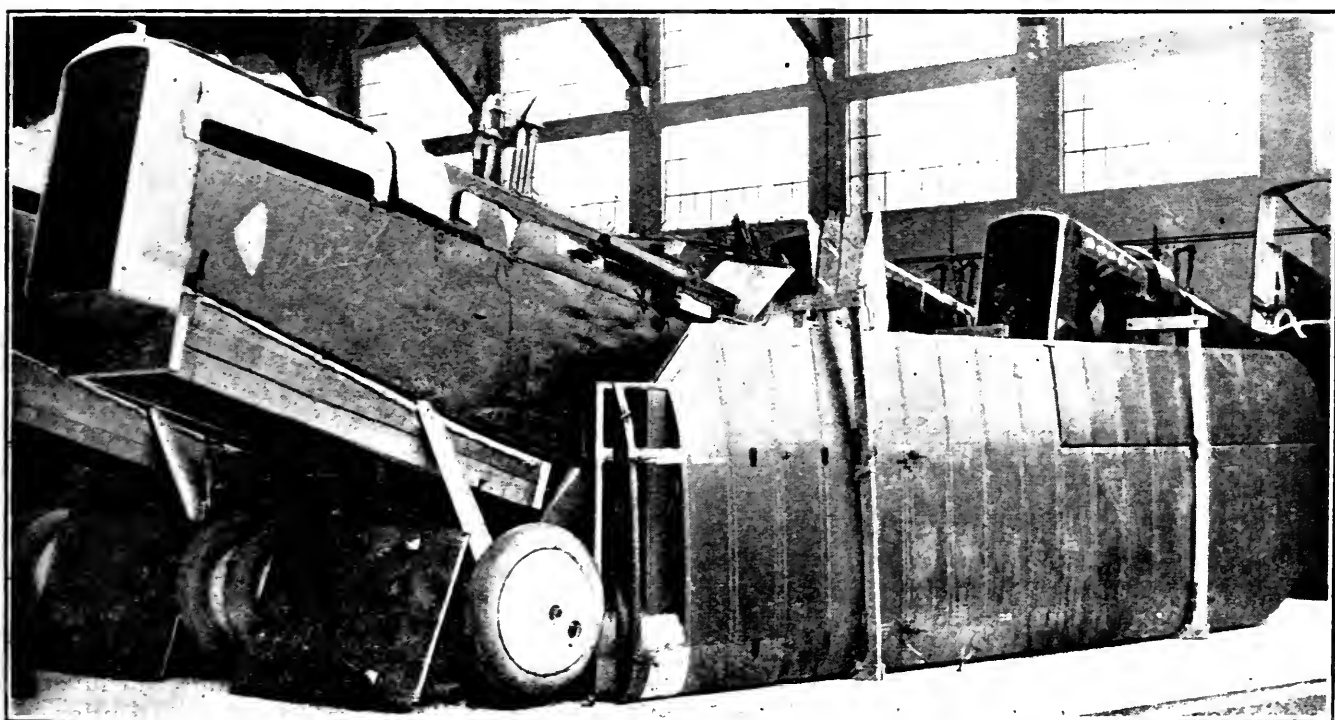


FIG. 15.—*Collective Storage of D.H.9; Positions of Components.*

stand the frames just clear of the fuselage. The smaller surfaces, such as the upper centre section, tail plane, elevators, are not so liable to twist, but they are equally liable to damage by puncturing of the fabric.

When leaning these components against the fuselage, that is, when the main planes are not accommodated in cradles, they should be inclined at such an angle as will ensure their remaining safely in that position. At a small angle to the vertical they may certainly be packed closer to the fuselage, but it is possible they may fall outwards if exposed to a draught of air or are inadvertently touched. This point is important in the case of centre section planes such as those of the Parnall Panther, which, containing petrol tanks and fittings, may be rendered useless by a fall.

In the case of those aeroplanes which are adjacent to a gangway, a clearance barrier should be placed around the outer components, that is, outside the main planes, so that these components are not damaged by traffic along the gangway.

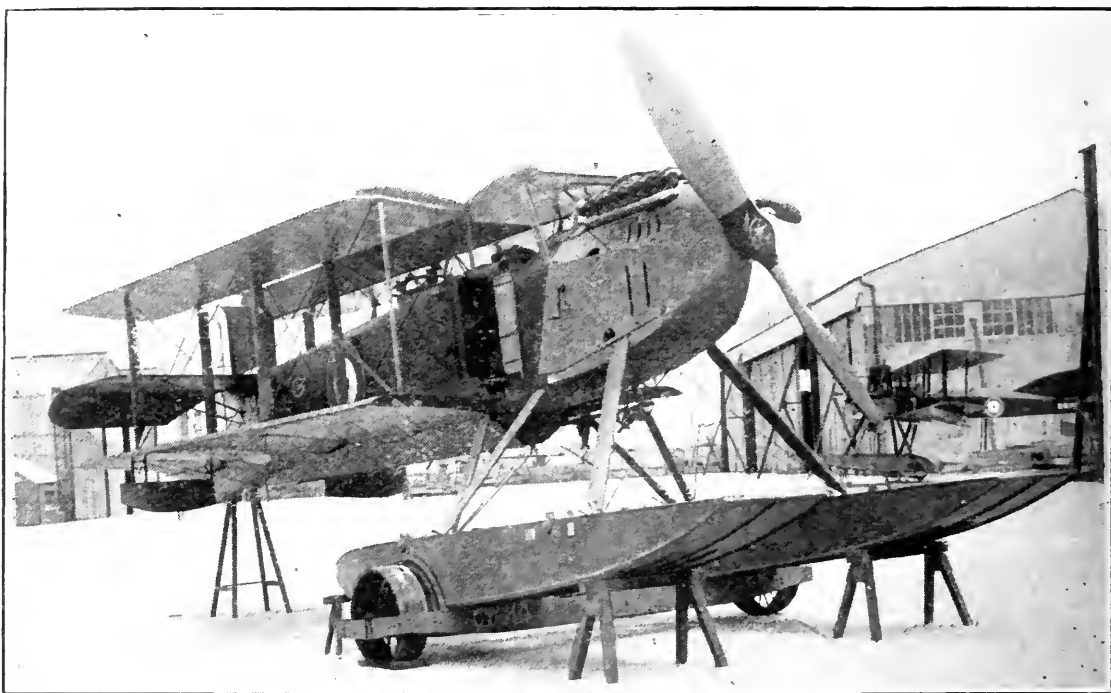


FIG. 16.—Fairey Seaplane supported with Main Planes folded.

This method of storage does not afford such convenient facilities for periodical inspection of the aircraft as the other methods described, but by suitable placing of the components, access may be gained to a fair proportion of the whole aircraft.

Seaplanes.

In the category of small aircraft there appear the smaller types of seaplanes. Most of these aircraft are, in construction, similar to a small aeroplane, but have substituted for the undercarriage a landing chassis composed of struts and watertight floats. In the main, therefore, the storage of a small seaplane must necessarily follow much on the same lines as that of an aeroplane of about the same size.

Apart from the features of design which are essential to a seaplane, there are the characteristics previously mentioned which call for special treatment for storage, namely, that whereas a land aircraft may not, apart from rain, be subjected to the effects of water, a seaplane has some of its parts continually under changing conditions of alternate wet and dry, and in windy weather it will be splashed with water practically over its entire surface, also the action of sea water is more detrimental to metal fittings than ordinary rain water, so that the protective

devices used on seaplanes should therefore be more efficient than those applied to aeroplanes.

Following on the lines of the previous notes, it is proposed to take a typical example of a small seaplane, and for this purpose the Fairey seaplane will be used. To enable a general idea to be obtained of this aircraft, it may be mentioned that it has overall dimensions of, span 46ft. 1in., length 36ft. 1in., height, with fuselage horizontal, 13ft. 1in. A crew of two is carried, and the main planes may be folded back along the fuselage. When on the water it is supported by two main floats, and the tail rests on another smaller float.

Being a small type of aircraft, it may be placed in store as a complete machine, and when so stored, the main floats may either be supported on a trolley or rest on battens on the floor of the shed; in both cases the fuselage will rest on a trestle placed under the tail float. The other parts of the aircraft are subject to the same usage as described for a Sopwith Snipe aeroplane. It will be unnecessary, therefore, to repeat the detail, and the considerations will be confined to those points which are peculiar to a float seaplane.

The seaplane is first located in an appropriate position in the storage shed, and to provide mobility for this operation the main floats are carried on a specially constructed trolley. This trolley, shown in Fig. 16, is built up of strong timberings, which form a framework 14ft. long and 3ft. wide, and is carried through an axle on two wheels. It is also used for transporting the seaplane to and from the water. In raising the aircraft from the ground on to the trolley, packing blocks of semi-circular section are used. The ends of the blocks are of semi-circular shape about 32in. in diameter, across which battens are attached. The diameters are boarded over to form a flat surface, and the length of the packing blocks is equal to the width across the main floats of the seaplane. To raise the aircraft on to the trolley, the tail is first lifted and one semi-circular packing block inserted with its flat top under the step of each main float, and with its circular portion on the ground. The tail is then lowered and the wheeled trolley pushed as far as possible under the front of the floats. The tail of the aircraft is now lifted again, and packing blocks placed between the semi-circular supports and the main floats, after which, by lowering the tail, the trolley may be pushed further under the main floats. This rocking operation is continued until the axle of the trolley is slightly in advance of the rear cross booms of the chassis, and in this position, with the aircraft horizontal, the weight will fall behind the axle of the trolley, so that a lift will have to be applied at the tail before the seaplane can be moved. In this particular type of seaplane, lifting handles are provided on each side of the tail float, and should be used for taking the weight at that point.

The seaplane having been placed on the trolley and moved to its correct position in the storage shed, it is necessary to reverse the order of the operations given above in order to lower the aircraft on to the floor of the shed. Before doing this some soft packing material should be placed on the floor so as to avoid damage to the main floats of the seaplane. When this operation is completed and a trestle placed under the tail end of the fuselage, the seaplane is in its correct attitude for storage.

For more compact storage the aircraft may be maintained in its complete condition, but will have its main planes folded. In this position the planes will lie along the fuselage as shown in Fig. 16.

Most of the features special to a float seaplane have now been covered; the remaining operations needed to complete the storage of such an aircraft will cover :—

- (1) Cleaning and overhauling the engine.
- (2) Emptying fuel, oil, and water tanks and systems.

- (3) Locking movable control surfaces and controls.
- (4) Cleaning down the whole aircraft.
- (5) Applying anti-rust and other protective preparations to various parts of the aircraft.

In carrying out these operations, the tops of the main floats should not be used indiscriminately as platforms for access to the engine, as the floats are of comparatively frail construction. In fact, it may be said that in the case of aircraft of this type the main floats are the most vulnerable portion, and when damaged, render the whole aircraft unserviceable. Along the top of the main floats in seven places are fitted screwed inspection covers, which have air holes pierced in them to allow of proper distribution of internal pressure when the aircraft is in flight; these covers should be left open while the aircraft is in store, and at the same time it should be seen that the air holes are clear.

The last operation is the application of protective preparations to various exposed parts, and it is necessary, in the case of this type of aircraft, to concentrate on this work. In use, the main floats and tail float are subject to a liberal splashing of sea water, and it is essential that all this water be removed before any protective preparation is applied. The exposed metal parts of the chassis may conveniently be wiped over with oil after the water has been removed and preparatory to the application of the protective preparation. A similar treatment should be given to all lower parts of the aircraft, comprising the lower main planes and tail unit, and the possible inroads of sea water should not be forgotten when dealing with the engine and the upper parts of the aircraft.

(To be continued.)

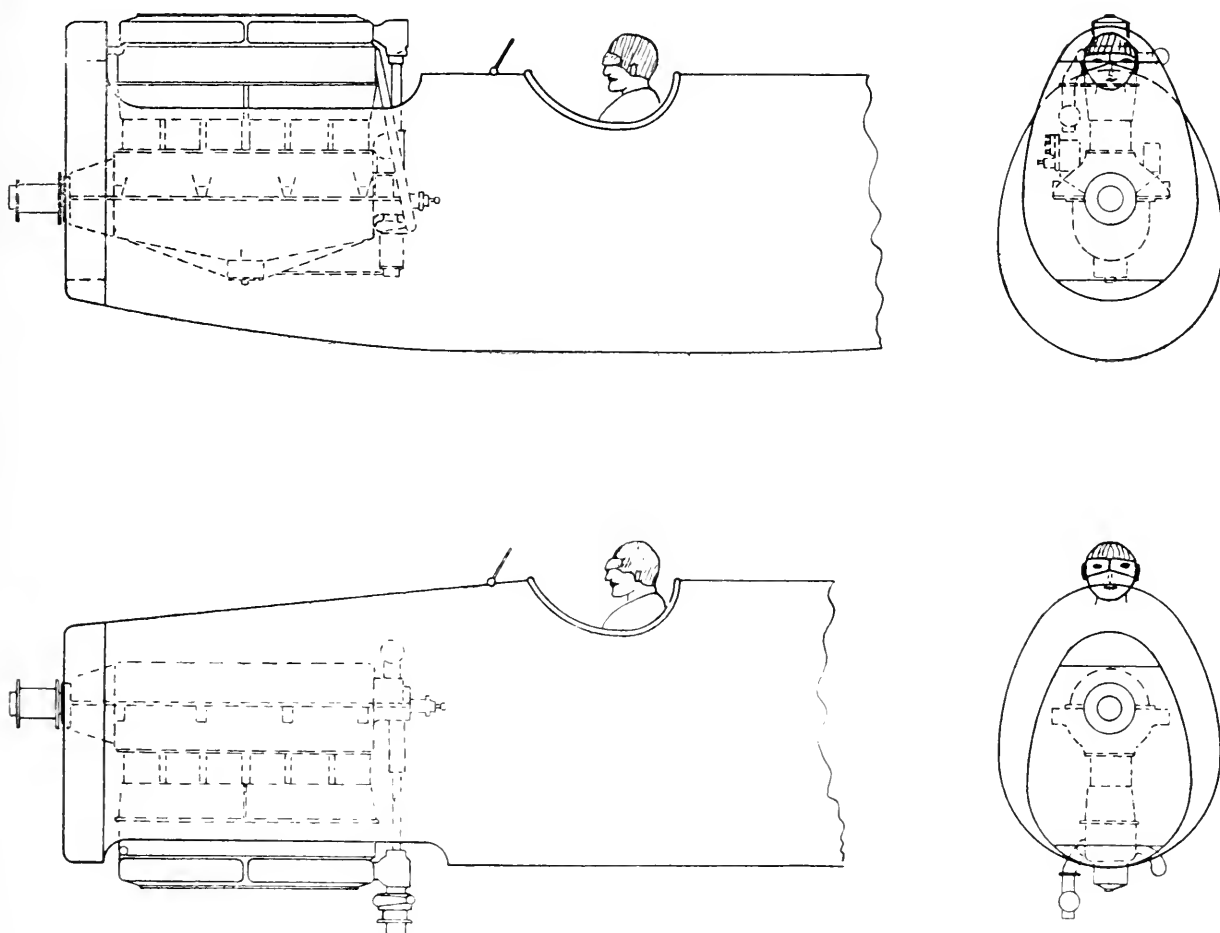


CORRESPONDENCE.

To the Editor of THE AËRONAUTICAL JOURNAL.

Dear Sir,—With regard to the interesting lecture on engine installation given by Brigadier-General Bagnall-Wild and reported in the April issue of the AËRONAUTICAL JOURNAL, it has long been a matter of surprise to the writer that more attention has not been paid by aircraft engine designers to the inverted engine.

Possibly the most important requirement of a fighting and reconnaissance machine is that it should allow the pilot the clearest possible range of vision. In the tractor type of aeroplane or seaplane, with engines as they are designed to-day, it is almost impossible to obtain a good view forward owing to the obstruction offered by the engine.



Some three years ago I had much pleasure, but, alas, little satisfaction in drawing the attention of the Air Ministry to the great advantages which would accrue, in the matter of vision, from the use of an inverted engine. I enclose some comparative drawings* which I then submitted. The inverted engine would do much to make possible the very desirable feature of a simple gravity feed petrol system which General Bagnall-Wild rightly advocates, whilst at the same time it would facilitate the leading away of the exhaust gases and lead to a greatly improved forward view.

There are several other advantages which aeroplane and seaplane designers will readily see, such as improved ground and water clearance for the propeller, etc.

Yours faithfully,
H. O. SHORT,

April 7th, 1922.

* One set only printed,—EDITOR.

OBITUARY.

SIR WALTER RALEIGH.

Aviation has suffered an irreparable loss in the death of Sir Walter Alexander Raleigh, the official historian of the War in the Air.

When the Royal Air Force became a separate arm of the forces of the Crown, taking rank with the Navy and Army, its tradition was already safe. But tradition is a great thing, and to exert its proper influence on a service it must be recorded and handed down from generation to generation to inspire them with accounts, fittingly told, of deeds of heroism and devotion to duty; and in the case of the Air Service of battles with the elements as well as with enemies—a story peculiarly its own, dealing with its own special trials—a story of the chivalry of the air.

The question as to whether there should be a separate Air Force is one which still stirs deep feeling, but this question has already been settled. The Royal Air Force has outgrown its pupilage to the older services and is now one of their partners. When it was officially decided that the history of the War in the Air was to be written, the Royal Air Force found its destined historian in Sir Walter Raleigh. During a discussion as to the form this history should take, he exclaimed, "It is a chance of a lifetime."

Before attempting his task Sir Walter decided to see something of the War in the Air. He proceeded to France on the 14th August, 1918, and returned on the 8th September. During that fortnight he was taken over the various headquarters and depots and saw what he could of the work of the Air Force under war conditions and made a keen study of the personnel. He was flown over parts of the front. Writing home on the 26th August, 1918, he says: "Now I am with a fighting squadron (for the first time) and I hope to get into a Bristol Fighter. The Camel and Snipe are not for me. I got right up to the front to see artillery working with aeroplanes, and I am on the way to understand sound-ranging, which is a wonder. Also, I am picking up the *Ac Beer Cee Don* language. . . . Where I am now we are bombed every suitable night."

He started to write the history of the War in the Air at the beginning of 1919. Its beginnings caused him considerable anxiety. He found official records scanty and bare. He planned and replanned the book. At first he only intended to devote a chapter or two to the pre-war period, but he soon realised that if the story was to be worthily told the history of the conquest of the air must first be dealt with. This involved considerable labour. A host of technical details had to be carefully studied. Not a fact would he accept without having previously mastered its significance. If he were told that the upper surface of the plane contributes most lift he would want to know why. On being informed that wireless reception in an aeroplane with the engine running at full power was first accomplished in September, 1913, he wanted to know by what special means, and before he left the subject he had made a study of wireless itself. The reported incident of an R.E.8 aeroplane flying itself for two hours with a dead pilot and observer led him into a detailed study of aeroplane stability and so on.

It is fortunate for aviation that Sir Walter, who only intended to summarise the early history, found himself drawn more and more into it with the result that about half of the first volume of the official history of the War in the Air is a classic on the art of flight itself. Aviation could have found no better friend,

no more enthusiastic student and no one more competent to tell the stirring story of the conquest of the air.

The following extract from a letter which he wrote at the very outset of his last great task is typical of what he felt to be his theme:—

“The humblest flier who went and strafed a Boche and got done in is not going to be sacrificed or even subordinated to the star performers. Every V.C. shall be clearly told that men who deserved it as well or better than he did are forgotten, in large numbers, because they faced certain death without witnesses. The hero of the book is chosen and is the Air, not the stars.”

After finishing his first volume he decided to carry out his visit to the eastern theatres of war—a visit which was originally intended to follow closely after his visit to France in August, 1918, but the Armistice intervened and the visit was deferred. The dangers of such a visit to his health were pointed out to him, but this only made him more determined than ever. It was for his book, the story of the Royal Air Force, and he would allow no real or imaginary danger to stand in his way. On March 16th, 1922, he left London for Port Said, travelling via Marseilles. He proceeded to Jerusalem and then to Amman. From Amman he was being flown to Basra when a forced landing had to be made in the desert owing to one of the three aeroplanes of the flight breaking down. A halt of four days was made under bad weather conditions. On arrival at Baghdad all was not well with Sir Walter Raleigh. He was next flown to Mosul. Here he contracted fever, for which he was treated, and he was advised to await proper recovery. But he wanted to get back to his work at Oxford so he returned to England while suffering from fever. He came back on the 25th April and not many days afterwards the fever had him in its grip. Typhoid was diagnosed and peritonitis supervened. He was operated on on the night of Thursday, 11th May. Although he rallied after the operation he died early on Saturday morning, the 13th May.

Sir Walter Raleigh had attained great distinction as an authority on English literature, as an eminent critic and as a pre-eminent stylist, before he took up with aeronautics. But it is the opinion of the author of this brief tribute that his fame will ultimately rest on the last literary achievement of his great life—the history of flight and the British Air Service. Although he only lived to complete one volume his services to aviation are outstanding. No man was better fitted to tell the story, in so far as words can express it, of the mastery of the air. No other man of mature years could have shown such youthful enthusiasm, such a wonderful grip of the temper of the air.

The author was only privileged to know Sir Walter Raleigh during the past three years in connection with the history of the War in the Air and does not feel competent to discuss his life and influences on literature. The object of these notes was to place on record some account of his work and devotion to aviation and the Air Service.

Walter Alexander Raleigh was born in 1861. His father was Dr. Alexander Raleigh, the Scottish Congregationalist divine. He was educated at University College, London, and King's College, Cambridge. At the age of twenty-three he was appointed professor of English literature at the Chief College, Aligarh. There he remained for two years, but for reasons of health he returned to England. His next appointment was assistant to Sir Adolphus Ward at Owen's College, Manchester. A year later, in 1890, he succeeded Mr. A. C. Bradley as Professor of English at Liverpool University. This post he held for ten years and during that period he earned a niche in the temple of fame by bringing out his books. “The English Novel” in 1894, “Louis Stevenson; an Essay” in 1895, “Style” in 1897 and “Milton” in 1900.

In 1900 Walter Raleigh was appointed to the English chair at Glasgow, again in succession to Mr. A. C. Bradley, and there he remained four years. During

this period he published "Wordsworth" in 1903 and "The English Voyagers" in the following year. In 1904 he was appointed to the new chair of English literature at Oxford. In 1907 he produced his "Shakespeare" and in 1910 "Six Essays on Johnson." He was knighted in 1911 and became a Fellow of Merton College, Oxford, in 1914.

During the war he was the moving spirit in getting good literature supplied to the troops by means of broadsheets. He firmly believed that English literature was the highest possible expression of freedom and in this he was right. In 1917 he produced his book "Romance."

In addition to writing some stirring appeals during the war, he edited the "Oxford Roll of Honour" after the war. Perhaps the most enjoyable years of his life were the last, when he was busy with the theme which fascinated and held the whole of his being. Never were his lectures so inspired as when his lecture theatre was crowded with the post-war students, many of whom were war veterans.

Concerning the history of the War in the Air, he said:—

"Some authors seem to seek fame; I shall be satisfied with forgiveness."

In this one line Sir Walter wrote his own obituary.

He was married in 1890 to Lucie Gertrude, the daughter of Mr. Mason Jackson. He leaves three sons and one daughter.



REVIEWS.

Notes and Examples on the Theory of Heat and Heat Engines. By John Case, M.A.

Professor Case has set out to write a book which should not be an exhaustive text-book, "but rather a companion to lectures, to help the student to see at a glance the important points of the subject, and to assist him with his revision for examinations." In this aim he has succeeded admirably and has produced at the same time a little book which will prove a handy work of reference to engineers. The subject matter is well chosen and the text clearly and concisely written. Any student who works successfully through the many typical problems given will have a very good initial knowledge of the application of the principles of thermodynamics to engineering.

Cours Pratique d'Aviation. By Capitaine Jambier and Lt. de Vaisseau J. Amet, Pilotes aviateurs. 1922.

The authors of this little book have undoubtedly succeeded in their aim, in treating the whole subject of aeronautics in a popular manner, avoiding wherever possible technicalities likely to confuse the youthful enthusiast. Some of the explanations given appear to be almost too simple; for instance, the treatment of stability is such as to leave the impression with the non-technical reader that the subject is no more complex than the explanation given. It should certainly arouse interest in the science of aeronautics, in the hands of any student, but whether sufficient space is devoted to the care taken in design, construction and testing to inspire confidence in a would-be aircraft passenger (as is hoped in the preface) is somewhat doubtful.

In treating the subject in a general manner the authors have avoided detail, but the classification of aerofoils into classes of nationality, for instance, as is done on page 7, rather than into types showing different characteristics, goes, it is felt, rather to the other extreme. The authors are to be congratulated, however, on the achievement of their main object in putting before the public a popular treatise on aviation.

La Photographie Aérienne. By André H. Carlier.

This work is one that should be studied by all interested in aerial photography, both past and present.

M. Carlier has dealt with the subject in a very comprehensive way; in fact, if a fault can be found, it is that the book is too comprehensive, as it starts with the theory of photography in the air, deals with restitution, goes into the subject of most of the cameras that were used by all the armies in the war, describes the organisation in the French Army of their photographic section, and then winds up in a very full way with the interpretation of aerial photography from the point of view of the general staff. Such things as stereo photography are also dealt with, and a table of separations, which is useful, is incorporated.

M. Carlier, very rightly from his point of view, imagines that the system and apparatus used by the French was the last word in the art, but with that I do not cordially agree. Such things as their standard changing box made by Gaumont, which were used to the end, were not very satisfactory articles, and although such cameras as the De Ram are illustrated, they were not functioning

in any quantity even at the end of the war, so that an opinion is difficult as to their practicability even now for use in the field.

Our own system of photography was based on supplying an apparatus which was fool-proof and of which the pilot or observer had little knowledge except to pull definite levers at definite times. The French effort was more individual, and I have even seen some of their cameras that had to be focussed! Provided suitable operators could be found some of their individual work was very brilliant, but the standard of work must be reckoned by the least successful, not by the most successful.

There is little mention of the long distance reconnaissance photographs taken on plates as big as $8\frac{1}{2}$ by $6\frac{1}{2}$ with a lens of a focus of six inches. These, when taken at 20,000ft., took in a perfectly enormous area and, although not showing great detail, were extremely useful to the general staff in showing general lines of defence that might be fallen back on.

The book deals very little with any other school of thought but their own, but to myself it recalls with pleasure the kindness of all the French photographic sections in showing us in the most unselfish way their very latest devices and schemes, many of which we adopted, though the interchange was not wholly one-sided.

The book is admirably illustrated, both from the point of diagrams and actual photographs showing camouflage.



THE AËRONAUTICAL JOURNAL.

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 139.

JULY, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Chairman-Elect.

At a meeting of the Council held on June 28th, Professor Leonard Baird, C.B.E., F.R.S., Fellow, was elected Chairman for the year 1922-1923. Professor Baird will assume office on October 1st next.

Examination.

The first Associate Fellowship examination, in accordance with the new regulations, will be held on Monday, September 25th (Part I.), and Tuesday, September 26th (Part II.), in the Library, at 7, Albemarle Street, London, W.1. Entries, accompanied by the prescribed examination fee, should reach the Secretary not later than Monday, August 28th.

Funds.

Full lists of subscribers to date of the R.38 Memorial Research Fund, Usborne Memorial Fund, and Pilcher Memorial Prize for Students are printed in this issue.

It has been decided to utilise the R.38 Memorial Research Fund as follows:—

- (a) To the placing of a memorial tablet in the Society's offices.
- (b) To the awarding of an annual prize of 25 guineas for the best technical paper on aeronautics, preference being given to those dealing with an airship subject. This prize to be open to international competition.
- (c) To the selection and collation of information on the development of design of airships to the present stage.

The balance of the income being allowed to accumulate at present.

The interest of the Usborne Memorial Fund is to be devoted to the award of a prize in every alternate year (unless the amount be such as to allow of an annual prize to the value of £10) for a historical paper on any aspect of aeronautics. This prize will also be open to international competition.

Detailed regulations for these two prizes are being drawn up.

The conditions of award of the Pilcher Memorial Prize for students have already been announced.

Office Closing.

The Offices of the Society will be closed from July 31st to August 14th inclusive.

W. LOCKWOOD MARSH, *Secretary.*

R.38 MEMORIAL RESEARCH FUND.

Donations Received to Date.

	£	s.	d.		£	s.	d.
H.R.H. The Prince of Wales, K.G.	10	0	0	Staff of U.S. Naval Attaché	4	10	0
H.R.H. The Duke of York	5	0	0	Mrs. W. Lockwood Marsh	3	10	0
Sir Alan Anderson	105	0	0	Lord Montagu of Beaulieu	3	3	0
W. H. Coates, Esq.	105	0	0	Major-Gen. Sir W. Sefton			
Lord Invernairn	105	0	0	Brancker	3	3	0
Rt. Hon. Lord Weir	105	0	0	Major C. C. Turner	3	3	0
Messrs. Vickers, Ltd.	105	0	0	Anon	3	0	0
Lloyd's Royal Exchange... ..	100	0	0	Major G. H. Abell... ..	2	12	6
Council of Royal Aëro-				Flight Lieut. F. M. Rope	2	2	0
nautical Society... ..	63	15	0	H. B. Wyn-Evans, Esq. ...	2	2	0
Viscount Cowdray	52	10	0	A. H. Ashbolt, Esq.	2	2	0
12th Squadron, Royal Air				A. P. Cole, Esq.	2	2	0
Force, Germany	43	7	3	Mrs. N. G. H. Hodgson...	2	2	0
Proprietors of "Daily				G. Reid, Esq.	2	2	0
Telegraph"	25	0	0	S. Payne, Esq.	2	2	0
An American Sympathiser	25	0	0	A. E. L. Chorlton, Esq....	2	2	0
Lady Shelley-Rolls	25	0	0	Squadron Ldr. D. Harries	2	2	0
Sir John Hunter	20	0	0	Major-Gen. W. Gwatkin,			
Flight Lieut. A. H. Wann	20	0	0	Canadian Air Force ...	2	2	0
Sir A. Denny, Bart.	15	15	0	H. B. Pratt, Esq.... ..	2	2	0
Mrs. E. M. Hilder	10	10	0	F. J. McConnell, Esq. ...	2	2	0
H. P. Marsh, Esq.	10	10	0	Anon	2	0	0
Sir H. McGowan	10	10	0	Flying Officer J. S. G.			
Staff of Royal Airship				Wrathall	1	10	0
Works, Cardington ...	10	10	0	Capt. Basil Miller	1	1	0
G. Holt-Thomas, Esq.	10	10	0	Flight Lieut. H. C. Irwin	1	1	0
Sir J. Maclay	10	10	0	Rev. Basil Phillips	1	1	0
Lord Glentanar	10	0	0	E. H. Lewitt, Esq.	1	1	0
V. Stefansson, Esq.	10	0	0	Major C. F. Abell	1	1	0
Griffith Brewer, Esq.	10	0	0	Col. Ivan Davson	1	1	0
Lord Foley	10	0	0	Major B. F. S. Baden-			
Lt.-Col. J. Dunville	10	0	0	Powell	1	1	0
H. E. Yarrow, Esq.	10	0	0	John Newton, Esq.	1	1	0
Lt.-Col. W. Lockwood				Comr. H. T. A. Bosanquet	1	1	0
Marsh	10	0	0	Sir Charles Bright	1	1	0
Mrs. Waterlow	10	0	0	"B.C."	1	1	0
2nd Squadron, Royal Air				E. R. Calthrop, Esq. ...	1	1	0
Force, Fermoy	9	0	0	Miss B. Haigh	1	1	0
47th Squadron, Royal Air				Sir Samuel Roberts	1	1	0
Force, Helwan, Egypt...	7	11	7	Flight Lieut. J. Barron ...	1	0	0
"From the wreck"	6	10	0	S. E. Taylor, Esq.	1	0	0
Staff of U.S. Military				S. H. Phillips, Esq.	0	10	9
Attaché	6	0	0	A. E. Marsland, Esq. ...	0	10	6
Lord Gorell	5	5	0	"J.T."	0	10	0
J. E. Hodgson, Esq.	5	5	0	Capt. A. E. Heatley	0	10	0
R. P. Wilson, Esq.	5	5	0	Capt. J. B. Walker	0	5	0
Mr. and Mrs. W. J.							
Anderson	5	0	0	Total	120	8	7
Sir Mortimer Singer	5	0	0	Interest on deposit up to			
Flight Lieut. A. S. Booth	5	0	0	31st Dec., 1921	2	6	1
70th Squadron, Royal Air							
Force	4	17	0	Total	£1211	2	8

PILCHER MEMORIAL PRIZE FOR STUDENTS FUND.

Donations Received.

	£	s.	d.		£	s.	d.
Sir Trevor Dawson ...	26	5	0	Sir Alfred Yarrow ...	10	10	0
F. W. Lanchester, Esq. ...	25	0	0	Sir J. C. Calder ...	10	0	0
The Pilcher Family (per Mrs. Tidswell) ...	25	0	0				
Walter G. Wilson, Esq. ...	25	0	0		£137	5	0
Lord Weir ...	10	10	0				

USBORNE MEMORIAL FUND.

Donations Received.

	£	s.	d.		£	s.	d.
G. Holt-Thomas, Esq. ...	25	0	0	Capt. G. Usborne ...	2	2	0
David Hawes, Esq. ...	10	10	0	Capt. C. V. Usborne ...	2	0	0
J. H. Mandleberg, Esq. ...	5	5	0	Air Cmdre. O. Swann ...	1	1	0
Wing Comr. T. R. Cave- Browne-Cave ...	5	5	0	Sir R. Threlfall ...	1	1	0
Air Cmdre. E. A. D. Masterman ...	5	0	0	T. A. Monckton, Esq. ...	1	0	0
Lord Rayleigh ...	3	3	0				
The late Air Cmdre. E. M. Maitland ...	2	2	0		£63	9	0



PROCEEDINGS.

ELEVENTH MEETING, 57th SESSION.

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, Adelphi, London, on Thursday, March 30th, the Chairman, Lieut.-Col. M. O'Gorman, in the chair.

The CHAIRMAN called upon Captain G. De Havilland to read his paper on "The Design of a Commercial Aeroplane."

THE DESIGN OF A COMMERCIAL AEROPLANE.

In order to keep within reasonable limits of a vast subject, I propose to discuss a typical commercial machine and to attempt to give some of the reasons which govern the choice of this particular type.

I hope these views on design will be freely criticised by those interested in transport services and thus bring about an exchange of ideas which must be of value to both operators and designers.

The object of aerial transport is the carrying of passengers and goods by air from one point to another in the shortest possible time consistent with:—

Safety,
Comfort,
Economy.

At the present time the type of machine is largely decided by the type of engine available, and as there are no very high powered engines suitable for commercial work, a large machine will necessarily be a multi-engine one.

The problem firstly resolves itself into what to do with a given engine:—

- (1) To build a multi-engine machine, or
- (2) A single-engine machine.

A multi-engine machine has generally been found in practice to cost more for construction than two single-engine machines using similar engines.

Among the reasons for this higher cost are the necessity for specially large sheds, the greater difficulty of handling larger units during construction, complication of engine controls and other reasons.

The large multi-engine machine also suffers from definite disadvantages from the service point of view, one of the most serious being that it must be more often out of commission owing to engine breakdown or adjustment, and being a large machine involves a greater financial loss while under repairs. Larger running sheds are necessary and the cost of handling on the ground and of salvage in the case of breakdown is relatively high.

Unless a twin-engine machine is much over-engined—and therefore uneconomical—it cannot fly on one engine with anything like full load. Therefore, if it has normal engine power and one engine cuts out it will be in nearly as bad a case as the failure of a single-engine machine, for the reason that although it can prolong the glide on one engine, it is not under good control owing to the side pull of the engine. It would seem, therefore, that under these conditions any supposed gain is at least open to doubt.

But if a machine carries two engines it must be nearly twice as likely to suffer from engine failure compared with a single-engined machine, therefore a twin machine must be more liable to forced landings.

The primary object of a twin-engine machine should be its ability to fly on one engine and therefore its comparative safety from forced landings. In this case the line of development would seem to be less weight per h.p. and a better arrangement of engine positions and improvement in control gear. The machine would then be easy to fly on one engine as regards control, and would at least give a very flat glide and allow the choice of a much greater area for landing.

It is very doubtful whether a machine of this type could be run economically at the present time, even allowing for a generous subsidy.

Although it is possible to make out a comparatively bad case against the twin or multi-engine machine, there are other conditions than purely economical and constructional which may govern the future development of the type. Public opinion may favour the multi-engine type although there is little or no reason at present why it should do so.

The only figures I have been able to obtain in connection with the relative reliability of twin and single-engine machines on the London-Paris service show that about 200,000 miles were covered by both types in a certain period and two forced landings occurred to both types involving some damage to the machines, but no injury to passengers.

There is little doubt, however, that the multi-engine machine will continue to develop together with the single-engine type.

If we assume the single-engine machine to be the more immediately suitable type, the problem then resolves itself into whether to build a large slow machine or a small fast one.

This brings us to the vital factor of wing loading, which requires very careful examination. *A relatively heavily loaded machine is fast, of low first cost, and economical to run and maintain.* It is therefore a desirable machine in every way, provided the higher landing speed can be safely dealt with and the "get off" is satisfactory. The relatively high landing speed can be dealt with in a satisfactory manner. The chief disadvantage to high landing speed has been the long run after touching, but this can be easily reduced to a reasonable figure by providing for a large ground angle so that the planes act as a very considerable air brake. Any reasonable landing shock can be dealt with by a good shock-absorbing undercarriage.

As an example, a test at Martlesham on a machine which has a ground angle of about 17° and a loading of 11.3 lbs. sq. ft. (R.A.F. 15 section) gave a pull up of 163 yds. in a five-mile wind. This type of machine has flown about 1,200 hours on service and there has never been a mishap which could have been avoided had the landing speed been slower. This is after all the best proof that the landing difficulties are practically no greater than in the case of a lightly loaded machine. Experience with wheel brakes has not given very good results. I witnessed a case of a large machine landing with wheel brakes in action. The pilot landed on a soft wet aerodrome and taxied over one hundred yards with the wheels locked, and it was found that the machine taxied almost as easily as with the wheels free. Some form of non-skid tyre might improve matters, but probably very little on a soft aerodrome. Wheels would certainly have to be made stronger and probably heavier to deal with the high stresses incurred by "breaking."

The large ground angle method of pulling up means a greater skid load, but this can be easily dealt with without incurring much extra weight.

The various methods which have been suggested for increasing lift and obtaining slower landing speeds have not yet been sufficiently developed to warrant a definite statement as to their practical value.

What is required to estimate this value is an answer in terms of a completed serviceable aeroplane to the following question:—"For a given 'get off' and

quantity of load, what increase of speed is possible over that obtained by existing methods?"

If one tries to visualise aeroplanes obtaining their lift from surfaces having much smaller dimensions than those used in modern aeroplanes, it is obvious that new difficulties will crop up, particularly in the matter of control. These difficulties might in many cases be insurmountable, or might be surmounted at too great a sacrifice when considered in the light of the question just asked.

It is necessary to specify a "get off" that will be safe under all reasonable working conditions, and this is probably best done by specifying a given height to be cleared in a given distance. We have made numerous full-scale tests with a view to finding out what constitutes a safe "get off" and to get a reliable method based on trials for predicting the "get off" of any type of machine. From these trials, and experience of actual service conditions, the limiting "get off" for fully loaded machines was that a height of 50 ft. should be reached in 450 yards from a standing start in a calm. This seems to be satisfactory in practice. These conditions can be fulfilled by a machine having a light loading and comparatively high weight, but this type has other disadvantages.

Taking a similar engine in each case, the lightly loaded machine is larger and therefore more costly. Shed space, handling, insurance, maintenance and depreciation are all more. Petrol and oil per mile flown are more, and larger tanks must be carried. The percentage loss of ground speed in adverse winds is greater owing to slower speed.

Against these disadvantages must be set the greater carrying capacity of the lightly loaded machine (if designed for the same "get off").

All these factors when balanced out against each other for 1,000 hours flying indicate that the passenger mileage is a maximum for a machine having a stalling speed of about 55 m.p.h., while owing to those costs which depend on the first cost of the aeroplane, the "all in" cost per seat per London-Paris trip reaches a minimum for stalling speeds between 58 and 62 m.p.h.

The machines with higher stalling speeds have, of course, the very great advantage of high cruising speed. There is in addition the fact that high speed will frequently permit of a whole extra trip being made in the day instead of just extra mileage as assumed above.

From the above reasoning it would seem that the best compromise at the present time is a comparatively small single-engine machine of fairly high wing loading. This machine, with an engine of 450 h.p., will carry about 2,000 lbs. of freight at a cruising speed of over 100 m.p.h., with a range of 350 miles. Whether this machine should be a monoplane or a multiplane is still an open question and actual full-scale tests only can decide the merits of each type.

We had looked into the monoplane type at various times theoretically and it seemed to offer only a moderate advantage over the biplane with most wing sections.

It seemed, however, that if the aerodynamic qualities were exactly the same as a corresponding biplane, the monoplane construction would be worth while owing to the smaller surface required and general fewness of parts making for a robust construction. In the preliminary lay-out it was found by integrating the forces on the various sections of the wing that a lift coefficient of about .7 would be obtainable. Later on, wind channel tests showed a distinctly better figure on the tapered wing used, and tests on the complete model demonstrated that the presence of the fuselage increased the lift so considerably as to bring the lift coefficient up to .86.

An estimate of the weight of wing structure showed that it was safe to expect the weight of the monoplane wing to be at any rate no more than the equivalent R.A.F. 15 biplane wing structure with an increase of speed range of about

10 m.p.h. The actual aeroplane has borne out these figures, as the weight of the wing structure is 1,050 lbs. and is equivalent to a R.A.F. 15 biplane structure of 740 sq. ft. loaded to 10 $\frac{1}{4}$ lbs.

It has not as yet been possible to get official performance figures, but from the tests carried out at the works, it is evident that there is a general agreement with the wind channel results. The loading with full load will be 17 lbs. sq. ft., most flights have been carried out at 15 lbs. sq. ft., and with this loading the machine lands at about 54 m.p.h. A speed trial at 10,000 ft. with this loading gave 116 m.p.h. Accurate tests are needed to confirm these figures, but it seems evident that the results expected from this wing construction are realised as near as possible and that this big jump in lift coefficient and consequent reduction of area can be translated from model to full scale without serious error.

This aeroplane has shown some interesting and difficult features. It was anticipated that the propeller problem would be a difficult one with existing gear ratios. This has been verified in practice and the need for lower propeller speeds is manifest. Small variations of the disposition of obstructions in the slipstream have a remarkable effect on the performance. The controls also have presented unusual features. The lateral control is very good, but rudder and elevator control are soft, while rudder control when taxi-ing is entirely absent.

The stability of this type tends to be more marked than the ordinary machines. Among the reasons for this are, doubtless, the facts that it has a larger range of angles of incidence and a smaller downwash than might be expected at slow speeds. Both these factors would tend towards fore and aft stability. Another practical point to be reckoned with is that in a commercial machine the space taken up by the spars in the cabin is rather large, and also the fact that spare wings are not so easily transported as is the case with a biplane. There is no doubt that every considerable increase of lift coefficient will produce difficulties which take some time to surmount. It is now obvious that the cantilever monoplane has very great promise, and it remains to work out the incidental difficulties in order to transform the promise into practical performance.

Construction.

It is difficult to find any advantages in metal construction at the present time for normal climates. The idea that it is safer than wood is not warranted by the evidence available. Metal construction is considerably higher in cost and it is liable to be heavier than wood unless excessive cost is incurred in construction, and it is probably less durable than wood when very thin metal and numerous rivets are used. This is partly owing to the difficulty of effectively protecting thin metal from corrosion. It will, of course, find its place in the future, but at the present cost alone puts it out of court. In tropical climates and climates having extreme variation, metal construction may be immediately necessary and the extra cost will then be worth while. Further data is necessary as to what actually happens to wooden machines.

The cost of commercial machines must be as low as possible, and this calls for the simplest possible construction. It can generally be assumed that the smaller the number of parts in any structure, the cheaper and safer it will be, and for these reasons a plywood covered structure is to be recommended. Plywood has the advantage of forming a substantial covering in place of fabric and at the same time lends itself to the construction of watertight bodies. A three-ply fuselage will stand a great amount of damage before collapse occurs, certainly more than a wire-braced structure. As a skin for both covering and bracing it is far preferable to sheet metal which, owing to its relative thinness, is very liable to dent and crack and is difficult to protect from corrosion.

Metal struts in fuselage or wing structure do not generally offer advantages over wooden members when considering simple and economical construction.

Wing spars are in a similar case, as it is at present impossible to standardise sizes of spars and thus make use of special metal sections.

There seems little doubt that wood construction will continue to hold its own for a considerable time in places where climatic conditions are fairly normal.

Rather than work on a very high factor of safety for the vital members of the structure and incur extra weight, it would seem preferable to allow for duplication of the stress path wherever possible. This does not always mean providing two similar members side by side, but rather by so arranging members that in the case of breakage of a part the stress is distributed in a possibly different manner and with a reduced factor of safety.

However strong a member is made there will always be a chance of failure through flaw or careless assembling. It might be a strained bracing rod with an internal flaw or the omission of a cotter pin in a vital place. In either of these cases complete failure of the structure might result if there was no form of duplication. Duplication may be carried out in many cases with the addition of very little weight, as in the case of making the incidence bracing in a biplane take the full load of either front or rear truss. Struts cannot be easily duplicated, but they are not subject to reversal of stress and are readily inspected. In the case of laminated members, such as spars, fuselage members and wiring plates, a very satisfactory duplication effect is obtained from the fact that they are laminated. These members can generally be designed so that the failure of one or more laminae does not involve failure of the structure. I certainly disagree with the principle of designing for a higher factor of safety and discarding duplication. I would suggest that a machine with a lower factor and complete duplication of members is considerably safer.

Controls.

The control mechanism is naturally of vital importance and calls for great attention in design both from the aerodynamic and the structural points of view. It will probably be universal practice in the near future to fit ball bearings to all controls. Ball bearing controls are easier to work and do not require constant lubrication, but a more important point is that they obviate backlash. This generally occurs in plain bearing controls, which are seldom lubricated (even if it is possible to do so) and the pilot reports the machine as "soggy" to fly. "Sogginess" generally means a certain amount of "lag" in control and a feeling of lost performance all round. I am strongly of the opinion that this feel is almost entirely due to bad control gear and that the actual performance in speed and climb is unaffected. It has been suggested that as machines get old the performance falls off. I have seen no evidence to support this, and from the few reliable tests that have come under my notice, it is apparent that there is no measurable decrease in performance in a machine that has been in service for two or three years. This is, of course, assuming that engine power and type of propeller are constant and that the weight of the machine has not seriously increased. It would be of great value if practical tests of this character could be carried out at Martlesham or Farnborough. Pulleys and fairleads sooner or later lead to fraying of cables. In cases where the control must be taken round a bend or corner a short length of cycle chain may be run over a smooth pulley with a suitable guard. This has proved satisfactory in practice. If control cables are fitted outside the fuselage, inspection and replacement is easier and the added resistance is hardly measurable. The chief line of development of control gear, apart from mechanical improvement, would seem to be the provision of more ample control at low speeds, especially rudder and elevator control. There is no trouble in making controls effective at high or moderate speeds, but there is room for improvement in their functioning at the lower end of the speed range.

In connection with lateral control, I think it may be of interest to describe briefly a device we have been developing during the past few months. Mr. A. E. Hagg, of our technical department, has been largely responsible for this invention.

The control stick operates chain sprockets located near each aileron through the medium of rods or wires. A crank on each sprocket carries a rod which operates the aileron direct. By setting these cranks at certain angles a differential action is obtained which allows one aileron to move up a greater amount than the other one moves down. This acts as a form of balance, and by varying the angle of the cranks any degree of balance can be obtained. It also has the advantage of reducing lift on the high wing more than increasing lift on the low wing, thus giving less tendency to yaw.

To take full advantage of this scheme the control stick should be high geared to the ailerons so that comparatively small lateral movement of the stick gives full aileron control with very little effort.

This device has been tried out on both monoplane and biplane and the results are highly satisfactory.

Engine Installation.

The detachable engine mounting does not seem to have proved itself necessary in service conditions; it may, however, be found very useful in the future when machines are run harder. It is in any case an advantage during construction and allows different engines to be installed in the same type of machine with the minimum amount of alteration.

Improvements called for in engine installation are of a practical nature and lie chiefly in providing greater accessibility and more robust design of details.

Cowling is always a difficult problem and the best method of treatment is to eliminate it as far as possible.

A matter that calls for immediate attention is the method—or want of method—of starting aero engines. It is not unusual to spend half an hour in starting up in cold weather and this is a serious matter on a commercial service. Electrical self-starters are, I consider, of little or no use and are dead weight to carry about. I see no reason why a suitable hand barring gear should not be satisfactory, providing the ignition and doping systems are improved for starting conditions.

Stability.

A commercial aeroplane must have a good degree of stability so that it can be flown “hands off” under all reasonable conditions. There is, of course, no difficulty in providing this degree of stability, but if the machine is stiffly stable, there will be more trouble in providing good control at low speeds. If the machine can be flown “hands off” under normal conditions, it should be possible to keep right way up when flying in fogs. Most pilots keep direction by steering by ground or other objective visibility (such as clouds) continually checked by compass. The actual process of rudder bar movement is practically subconscious, so that when all objective visibility is removed, as in a fog, the pilot has no guide of direction except the feel of position of the rudder bar. But this trouble will probably be eliminated by the use of a suitable turn indicator and in connection with this it might be an advantage to have a temporary hand-operated rudder control for use in fog conditions.

Petrol Systems.

The best possible petrol system is one in which the tanks can be so placed that the flow is entirely by gravity. Owing to carburettor design it is seldom possible to take advantage of this system as a considerable “head” is required

to ensure sufficient feed when "getting off." It would be a definite gain if engine designers could provide carburettors that would work on a much lower "head" than at present. The pressure system is generally rather lighter and simpler than the petrol pump system, but there is not much to choose between them, and both entail considerably more weight and complication than gravity feed.

The position of petrol tanks on the wings has the advantage of less liability to fire in the air and also in the case of a crash.

Probably the safest place is under the top plane, just outside the slipstream, as this is a part of the wing structure that is often undamaged in a crash.

Rubber joints in the petrol system are undoubtedly a cause of trouble, soft steel piping seems to be reliable and also Petroflex tubing, which has the advantages of a flexible tubing and is at the same time durable.

Accommodation of Passengers.

The passenger cabin is generally arranged with two rows of seats with a central gangway. This is preferable to a three or four row cabin from the point of view of passengers' comfort, owing to all seats being window seats.

The best form of seat at present is the specially designed wicker type. A good wicker chair is light and strong and will stand the wear and tear involved by continually clearing the cabin for carrying goods. When there is no longer any necessity of making a machine to carry both goods and passengers it will be possible further to improve passenger accommodation.

The decoration of the cabin is largely a matter of taste, but at the same time it is most important to have a durable colour scheme that will not be easily tarnished. This is, of course, more difficult when the cabin may also be used for carrying goods. Weight of decoration must be carefully watched.

It is easily possible to throw away 100 lbs. in paint and varnish and this means a loss of from £5 to £20 per day in load, according to the class of freight lost.

The cabin should have a minimum height of 6ft. 3in. and should be clear of obstructions. Ample window lighting is necessary and at least two windows aside should be made to open. An emergency exit of large dimensions is best arranged in the rearmost part of the cabin, as in this position it is well clear of the water in the case of a forced descent.

Engine noise can be considerably reduced by arranging suitable bulkheads between engine and cabin. Exhaust silencing does not present serious difficulties, long pipes with a suitable method for diffusing the gas at the point of exit behind the cabin seem preferable to bulky silencers. Most silencers are very liable to burst when pumped full of petrol vapour when starting up. This is not the case with long pipes.

As there is practically constant air velocity when travelling, it should be possible to arrange for good heating and ventilation systems. Provided heat is taken from a part of the exhaust pipe sufficiently far from the engine, there should be no trouble from devitalised air. It should be possible to provide an ample supply of fresh air with a wide range of temperature.

The luggage compartment should be of large dimensions and entirely separate from the main cabin. It is generally found convenient to arrange it immediately behind the cabin with a door provided in the side of fuselage.

It may be interesting to review the capabilities of a modern type of single-engine commercial machine. I venture to suggest that such a machine has much greater durability than is generally supposed, and that the cost of maintenance of the aeroplane is extremely small. These factors will probably come to light in the immediate future and will no doubt have a healthy effect on the development

of commercial aviation. A modern type commercial machine is capable of hard service for at least three years and probably much longer; taking it at the lower figure this means a distance of well over half a million miles. The present mileage between engine overhauls is from 15-20,000, which compares with any type of motor transport.

As regards maintenance, experience has shown that amongst the chief items of expense are:—

- The renewal of control cables owing to fraying.
- Replacement of rubber shock absorbers.
- Replacement of the wearing parts of petrol pumps.
- Tail skids.
- Landing wheel tyres.

All these troubles have been eliminated in the latest designs except the last, and the use of solid-tyred wheels is now receiving attention. Maintenance costs should be much less than they were even six months ago.

If we leave out of consideration any aerodynamic or structural improvements that will probably appear in the near future, the result of steady development on normal lines gives every reason for an optimistic outlook. With the appearance of larger and lighter engines the cost of passenger or ton mileage will further decrease, and owing to greater reliability the dangers of forced landings will be practically non-existent.

The London-Paris services will be the subject of much interest during the present year, and it is the experience gathered in running these services that will chiefly govern the future design of the commercial aeroplane.

My thanks are due to Mr. C. C. Walker for his assistance in preparing this paper and especially for those notes referring to the monoplane.

DISCUSSION.

Major F. M. GREEN dealt first with metal construction, and did not agree with the Author's remarks in this connection. He admitted that at the present moment it was expensive to make metal aeroplanes, because we did not know altogether how to make them. It was very expensive to make wooden aeroplanes at the beginning, and we had to acquire a certain knowledge of technique in the use of wood before we got the weight of wings down to what they were to-day and of the requisite strength. We had already made metal planes which were no heavier than the lightest wooden planes that could be made, and he was pretty sure that we should make planes a little lighter, with the same strength, in steel or other metals. Also, he had reasonable confidence that in the not far-distant future they would be made at no greater cost, and it was even possible they might be cheaper. One of the chief drawbacks to wooden wings was in the cost of the wood itself; a lot had to be wasted in order to pick out the best, and that ran away with a lot of material. As to durability, he did not think we should have any serious trouble in using very thin sheet metals. The sheet metals used were not of paper thickness, as some seemed to imagine, and it was possible to protect them without very great increase of weight. Again, it was possible that we should use stainless steel in the future, which would add to durability, and we could even now afford stainless steel of proper quality at a reasonable price. With regard to multi-engine machines, he agreed that it was no good having a multi-engine machine if they could not fly on one engine. He suggested that a three-engine machine might help, because then, if one engine stopped, they could arrange to have two-thirds of their power, whereas now if one engine stopped, they only had something less than half, because, among other things, there would be increased drag in using the controls

to make an aeroplane fly straight. Twin-engine machines were awkward in many ways. It seemed to him that there were possibilities of using what he might call multi-motor units. By that he meant mounting possibly three engines on a single crank-case in such a way that they could fly on two engines without any extra resistance. That was a problem on which he was working at the moment, and he daresay others had views on that subject. It seemed to him that if they could make a multi-engine unit in which the auxiliaries, such as petrol systems, were entirely separate and distinct, in order that they could use any two engines, they could carry on quite well if one engine stopped because they would then have about two-thirds of the power left, which was about the average horse-power which the average machine to-day flew on. He quite agreed that the reliability of the present machines was considerable; engines did not break down very often, but forced landings did sometimes happen, and on that account pilots would not fly in that particular part of the atmosphere which was most suitable. If they could have engines which were, to all intents and purposes, infinitely reliable, they would be making a great step towards, at any rate, reducing insurance charges in connection with commercial aviation. With the rest of the paper he agreed entirely, and the Author had made a very valuable contribution to the subject.

Mr. W. O. MANNING, speaking of landing speeds, said he noticed the Author referred to a machine with a R.A.F. 15 section and a loading of 11.3 lbs. sq. ft., which presumably meant a landing speed of somewhere about 65 miles an hour. He himself had always looked on the question of low landing speeds as being a sort of guarantee against too much damage in the case of a bad landing, caused either by a bad aerodrome or a mistake on the part of the pilot. One remembered that years ago Bleriot built a series of monoplanes with 25 h.p. Anzani engines, and these machines had a very heavy wing camber underneath as well as above. The landing speed was probably about 27 or 30 miles an hour. Lots of people took tosses on these machines, and only in a few instances were people seriously hurt. After that, Bleriot sent out a similar series of machines fitted with 50 h.p. Gnome engines, and with considerably less camber on the wings and with a considerably higher landing speed. If they took a toss out of one of those machines they were almost certainly pretty badly hurt. There was no doubt that if they always assumed a good aerodrome and a perfect landing on the part of the pilot, they could run the speed up to anything they liked. If, on the other hand, they had to assume that the pilot was occasionally going to make a mistake, or that they had to land on a bad aerodrome, then they must not land at too high a speed, because otherwise there would be too much risk of damage both to the plane and to the passengers. He quite agreed with Captain De Havilland on the question of metal construction. Stainless steel would undoubtedly come in the future, and when it came it would remove many objections to metal construction; but he doubted even then whether such things as spars would be completely rustless. It was not easy to see how one was to make rivets, for instance, rustless, unless they were prepared to heat-treat each spar after it was made. Even then it would be difficult, because there would be a certain amount of damage caused on the surface of the rivet by the hammer, and this would result in rust. As one went on, one devised improved methods of constructing wooden spars; wood construction had one important advantage, because it was possible to taper a beam of wood from one end to another, and therefore get ideal conditions of disposition of material, which they could not do with steel, although, to some extent, by rivetting different pieces of metal together it could be done, but it was not quite the same thing. He preferred, for interplane struts, to use steel tubing; as far as his own experience went, steel tube struts with socketed ends were cheaper than wooden ones.

Squadron-Leader R. M. HILL said the paper had appealed to him particularly because of its essentially practical nature, and as a pilot he felt that papers which

keep severely to the practical side help so much. Captain De Havilland had made a comparison between the single and multi-engined aeroplane, and had taken as his text "safety, comfort and economy." They would all agree that safety was the greatest of these, because without that economy lost a good deal of its force. He himself, however, rather felt, if he might be allowed to say so, that the comparison was a little unfair. What mainly concerned the pilot was whether he was going to have a complete cut-out or not. The twin-engined aeroplane was far more liable to a partial breakdown than a single-engined aeroplane, but the chance of both engines going wrong and leaving the pilot in the air without any engine at all was very much less; and he ventured to maintain that the difference between having one engine to help him to glide to some landing space and having no engine at all made all the difference in the world. The greatest danger was when he lost his only engine, and he (the speaker) felt also that the twin-engined aeroplanes they had been largely accustomed to were the war type, which were very heavily loaded, and of relatively high power. The size of a twin-engined aeroplane made it clumsy, and he felt that if they had twin-engined aeroplanes more lightly loaded they would not get nearly the same effect when one engine cut out; and with a certain improvement in aerodynamic design they might get along quite well. The twin-engined aeroplane had a bad time, largely because it was heavily loaded. He (the speaker) could not view with equanimity the bringing up of stalling speeds to 52 and 55 m.p.h.; the pilot's task was already hard enough. He quite realised that it was much more economical to fly with heavily-loaded machines, but to get a short landing run the aeroplane had to be made with a large angle of incidence with respect to the ground. That involved a high undercarriage, and pilots did not like high undercarriages. Sitting in the aeroplane at a large angle to the ground, the pilot had a relatively poor view, and when getting off, if he encountered any ground bumps, the aeroplane felt top heavy. He (the speaker) always liked aeroplanes with low undercarriages, and wings very close to the ground; when landing they seemed to cushion along the ground, and landing seemed much easier altogether. He very heartily agreed with that section in the paper with regard to control gear. He believed that much of the soggyiness of controls was due to the haphazard way of fitting them up, and if we had larger pulleys than were used nowadays we should get rid of fraying of the controls, and feel that the controls were working better. Nowadays the pilot could very often not distinguish between a control being aerodynamically imperfect and mechanically imperfect. He endorsed all that was said by the Author as to petrol systems. It should not be necessary for a pilot to sit for three hours trying to learn a petrol system before going up, and it was a considerable mental strain to operate various cocks and to keep an eye open to see that they did not get inadvertently turned off.

Mr. F. HANDLEY PAGE thoroughly agreed with several speakers who had referred to high landing speeds and the consequent increase in the possible danger to the occupants of a machine. He had been discussing this matter with the insurance companies in an endeavour to get premiums reduced, and was informed that if landing speeds could be kept below 50 m.p.h., there was a considerable possibility of lower rates being quoted, as they seemed to be of the opinion that an increase in landing speed was accompanied almost invariably by an increased risk of damage to machines and to the occupants. On the other hand, if they wanted economy at top speed and at cruising speed they must load their machines to a very high degree, *i.e.*, 9, 10 or 11 lbs. per sq. ft. The only solution of the problem seemed to be that of the slotted wing.

He agreed with the Author on the question of metal *v.* wood construction, and he always considered they had an analogy in light boats. They might build a "Lusitania" or other large craft of steel, but practice in connection with motor-boats was almost invariably to build them with wood. In aircraft they must have a body, with a skin to protect the passengers, and if they could make

it one that took the forces and the loads at the same time, then it was possible they might make it lighter while still giving the passengers comfort. That was hardly possible in metal unless they had an ordinary girder structure and covered it with thin material. Therefore he believed on the balance, for the loads to be carried and the sizes of machines at the present time, wood was preferable, and would hold the day for a considerable time over metal. He had been told that during the war the Fokkers which were used in Turkey and other places in the East, where they had very considerable differences of temperature, were built of wood, in a similar manner to those used at the present time, and they experienced no difficulties due to warping or other distortion of the planes, provided the wood was properly treated; he was assured that therein lay a very special secret of the Fokker Company. For some time to come he felt that wood would hold the day.

As to multi- and single-engine machines, to a very large extent the trouble with any engine or engine system lay, not in the engine itself, but in the installation; that was fairly widely admitted. Therefore, if they could get, for a multi-engine machine, a very simple petrol system which consisted of one big tank in the air, with a 5in. pipe and the engine below it, with one tap only to turn off, there was very little to go wrong, and very little chance of the pipe being stopped up (laughter), which was really what they wanted to come to. If they wanted to get the necessary head, the tank must be some distance above the top plane; but if they could evolve a system whereby the engine installation did not require a complicated pressure system or complicated petrol pumping systems, he believed the multi-engine machine would hold the day. The possibilities, then, of anything going wrong were very largely eliminated, and if anything did go wrong they would have another unit to carry on with. The best advantage of all in a twin-engine machine was that the pilot and passengers could have a better look-out than when the engine was in front. He remembered that some passengers who had travelled in a Farman machine—being unable to get accommodation elsewhere (laughter)—commented upon the excellent view they could obtain from the windows at the front, the pilot in that case being in between the planes.

Major R. H. MAYO said that Captain De Havilland was really the pioneer of the heavily-loaded, high landing-speed machine, and when he had the courage to introduce the first DH4 machine he did a service of enormous importance to the Allied cause. The machine was a very great advance on any previous machine of the same type and for the same functions, and it was very largely because Captain De Havilland had obtained such a big increase in performance at the sacrifice of landing speed. For war purposes he had demonstrated that that sacrifice of landing speed was worth while, but he (the speaker) did not think it had been demonstrated that the heavily-loaded machine was the right type of machine for commercial purposes. Since the war, the British designs had been almost exclusively of the comparatively heavily loaded type, and in this country we had had no real demonstration of what a lightly-loaded machine could do. The Author had made a very remarkable statement. He had said, referring to a single-engine, heavily loaded machine, "This type of machine has flown about 1,200 hours on service, and there had never been a mishap which could have been avoided had the landing speed been slower." That was a very fine record, but he did not think it was quite the whole truth. It was certainly true that there had not been many accidents, but what had been the effect of this high landing speed on the regularity of the service? How many times had journeys between London and Paris to be cancelled because the machine was not suitable for the journey under adverse weather conditions? Of all the conditions that were difficult to deal with on this particular route, fog was the worst; this winter we had had a spell of many weeks when fog was prevalent, and the services had been very seriously interrupted. He ventured to think that fogs were not

an insuperable difficulty, but that many modern machines were too dangerous to negotiate a forced landing in foggy conditions. The fact of the matter was that the pilot knew he would have to fly at a low altitude, and if the engine failed he would probably have to land in a very limited space, which he could not do safely on a heavily-loaded machine. He knew that on an aerodrome he could pull up in, say, 163 yards, or whatever it was, but to achieve that on a forced landing across country, where there were probably obstructions, was a very difficult matter. There was no stretch of country between London and Paris where they could hope to negotiate a forced landing with a machine landing at 60 miles an hour with any reasonable degree of certainty. That was the thing that was in the minds of the pilots, and it had the effect of enormously reducing the regularity of the services. That irregularity was a very serious handicap. Only when services ran systematically, whatever the weather, would the public have confidence in them, and although fog would always be difficult to cope with, the difficulty would be very greatly reduced when we had machines with reasonably low landing speeds. During last year he had had a good deal of experience with the French machines, and one machine in particular had given a very good demonstration of the value of low landing speeds; that was the Farman "Goliath," which had easily the lowest landing speed of all the passenger machines now operating. Although numerous engine failures had occurred on this type of machine, it had a remarkably good record on all the services, for the reason that it could negotiate forced landings. As an illustration of what the machine could do, Major Mayo mentioned that during the competition for the French Grand Prix last year the "Goliath" was forced to land by engine trouble in very broken country at night without landing lights and without any external assistance. It landed successfully, but only because it could land slowly. The pilots had to negotiate altogether three such forced landings at night during the circuit of France, all of which were successful, and eventually this machine won the prize. That was rather a severe test, but it showed what could be done with a machine of low landing speed, and that such machines would be able to face foggy conditions on recognised routes in the day-time.

The Farman "Goliath" illustrated a remark made by Squadron-Leader Hill, which he (the speaker) thoroughly agreed with—that the value of a multi-engine machine would depend to a great extent on the aerodynamics of the machine and on the question of loading. This was a case in point; the Farman "Goliath" was a twin-engined machine, and that fact had been of very great value, largely owing to the machine being lightly loaded. He had been talking, a few days ago, to a French pilot who had started from Rotterdam for Brussels. Five minutes after starting one of his crankshafts had broken, but he was able to carry on with his full load for a distance of over 80 kilometres and land safely at Brussels. That showed how a lightly-loaded machine could make use of the fact that it was a multi-engine machine; in point of fact, the second engine had often just made the difference with such machines.

Referring to petrol installations, he remarked that in France the gravity tank had been almost universally adopted; nearly all the post-war machines had gravity tanks on the top planes. But that was not necessarily a safeguard against fire, unless the details of the installation were carefully attended to. He gave an illustration of how a machine had recently been destroyed by fire due to faulty installation, in spite of the fact that all the petrol was contained in tanks on the wings and well clear of the fuselage. In this case the pilot had not been provided with an adequate means of shutting off the petrol after the fire had started.

Colonel W. A. BRISTOW dealt with the conditions in commercial machines for the pilots, and said that he would like to see pilots in the middle of the cockpit, so seated that they could see equally well on both sides of the machine. The present conditions were a great drawback when taxiing, because some aero-

dromes to-day were very imperfect. It was also very difficult for a man who had to make a forced landing on a single-engine machine when he could look only on one side. Having got the pilot fixed in a position so that he could see well on both sides and in front of the machine, they had to consider the first essentials for safe operation. There was first his compass. After seating him in a good position in relation to the controls, which should be adjustable, because there was a very great difference in the size and length of reach of commercial pilots to-day, and providing him with a compass in a place where it could be easily read in all circumstances, the question of the wireless gear arose. Generally, when a machine was finished, an engineer came from Marconi's and tried to find a place to put the gear. He would hang it all over the cockpit, like a Christmas tree, and then the pilot must take a mechanic because he could not wind out the aerial himself. The wireless installation should be so arranged that the pilot could work the whole thing himself, and he (the speaker) was sure that they would not get the best results out of wireless on aeroplanes until the pilot could work the installation himself. The good results obtained with high landing speeds were probably due to several reasons which really should not be allowed to persist. In this country very good results indeed had been obtained from the operation of, for instance, the DH18, which had proved itself to be safe in operation. But there was the fact that we had reduced commercial aviation in this country to almost a highly specialised science. The requirements of the machines had reduced commercial pilots to an extraordinarily small number, and it was becoming an extraordinarily difficult matter to find a pilot that we knew would be perfectly safe in all weathers in some types of machines now operated. In France there was one line operating a heavily-loaded machine, which had 15 per cent. forced landings over six months. The number of machines that crashed was appalling, and there were several fatal accidents. Another machine, the "Goliath," which had 14 per cent. forced landings over the same period, had not recorded, so far as he knew, a single injury to a passenger, and there the pilots were far more numerous, and, in the main, not what one would term the highly specialised first-class pilots of which our little band of pilots in this country consisted. Something would have to be done to make the operation of machines more comparable with the working of high-speed locomotives, or a ship. There was no doubt that the number of journeys which could have been undertaken had been very seriously curtailed by the fact that the machines available were not of the type that could be safely sent off with passengers in the sort of weather they might have had to encounter.

The CHAIRMAN said they had had two or three acutely interesting problems put before them by Captain De Havilland, but one was perhaps more acute than the others, namely, that of the heavily-loaded machine *v.* the lightly-loaded machine. That would resolve itself practically in the future, because he believed the Author's scheme was the scheme which would eventually take its prime position when the power unit no longer broke down. No argument had been urged against the heavily-loaded machine, except that the engine was liable to stop, so far as he could gather, and therefore it was just as well that they had amongst them an engineer of foresight who was working for that time. The other big question of metal *v.* wood was raised, and he did not think that in this case the issue was joined quite so strongly, but his personal view favoured Captain De Havilland's, partly because he thought it would be essential for many years to come that civil machines should be convertible into war machines, and for war machines a high rate of replacement of wastage was cardinal, and the rate at which they could work on wood was incomparably greater than that at which they could work on metal. He defied anybody to rivet up a wing at the same rate as that at which they could build up a structure in wood.

Captain DE HAVILLAND, replying to the discussion, dealt first with Major Green's remarks as to metal construction. He quite agreed that metal con-

struction would eventually find its place, but the trouble now was that the time factor was important, and he should think that metal machines must take three times as long to build as wooden machines. There was no doubt that they were very much more difficult to build unless they had quantities running into hundreds probably, and that was very unlikely for a very considerable time. But wood had other advantages, and there was one big advantage in the case of a wooden machine if it were far away from its place of manufacture. A metal machine was much more difficult to repair than a wooden machine; if a wooden machine needed repair they could generally get the wood and a man to repair it, which was not the case with a metal machine, especially when using high-grade steels, which were difficult to obtain. He had not heard anyone really give a reason why machines should be of metal, except for use in the tropics, where it might be essential, but in normal climates there did not seem to be any great call for metal at present. Above all, in these times commercial machines must be cheap, otherwise it would be difficult to start any air lines at all. Major Green had also mentioned multi-engine machines. He was glad to hear that he was working on a multi-engine unit because that was another line of development which would probably bring good results. But if one set out to design a commercial machine at the present time, one could hardly consider a multi-engine unit because none existed in a tried-out form. Mr. Manning had spoken of landing speeds. It was a difficult question, but it seemed to him that machines with a loading of 10 or 11 lbs. per sq. ft. (R.A.F. 15 section), which certainly had a touching speed of 63 miles an hour, were not anything like so dangerous as some speakers had suggested; really the proof was in the experience we had had during the past two years of highly-loaded machines flying daily on the London-Paris service. Certainly there had been very few accidents, and he knew there had been several forced landings successfully made in fairly small fields. One would naturally go for a landing speed of 20 miles an hour if possible, but it would be very difficult to make a cheap or fast machine. Squadron-Leader Hill had mentioned a large ground angle as being bad. He (Captain De Havilland) really did not think there were any disadvantages in the big ground angle as the pilot would soon get used to it. To look at the matter of high loading from the point of view of high landing speeds was rather the wrong way to look at it. After all, the main thing was the run after touching the ground. It did not matter very much whether you touched at 50 or 60 if you ran practically the same distance. It would be quite interesting to test the run of a highly-loaded machine with a big angle against another machine with a reasonably light loading. He believed it would be found that a highly-loaded machine with a big angle would pull up in almost the same space as the lightly-loaded machine. Mr. Mayo had also discussed high landing speeds and the danger of fogs. He (Captain De Havilland) believed that in a bad fog any machine was dangerous, and there again he did not see that it mattered very much, if they were going to hit the ground in a fog, whether they hit it at 50 or 63. In any case it would be rather bad, and if the actual run was very little greater in the heavily-loaded machine he did not see any great difference. As to the Farman machine which was said to fly with full load on one engine, did anyone seriously believe this was possible? As to gravity feed, it would be a great advantage if engine designers could so design carburettors that they would work at a head, say, of 6in. instead of 3ft. In most ordinary-sized machines it was almost impossible to get the petrol tank high enough, and therefore they had to go back to the application of pressure or pump feed. They found that where a head of 2ft. was specified as being sufficient the acceleration of the machine generally upset the flow, and it really meant a head of more like twice the amount. With regard to Col. Bristow's suggestions that better provision should be made for pilots, the one trouble in putting the pilot in the middle of the cockpit was that very often the navigator was wanted at the side of the pilot. That had been often specified and made it very difficult, because the pilot had to be put at one side. As to compasses and wireless gear,

he could only suggest that in the latest machines that had been designed they were in a better position.

A hearty vote of thanks to Captain De Havilland terminated the proceedings.

NOTES ON CAPTAIN DE HAVILLAND'S PAPER.

There are several statements in Captain De Havilland's interesting paper which are distinctly debatable.

The first is the relative cost and reliability of a large multi-engine machine compared with a number of small single-engine machines of the same total carrying capacity. The large machine is fundamentally cheaper per lb., as the number of manufacturing operations will be smaller; actually the number of large commercial machines constructed has been so small that they are practically all experimental models.

Regarding reliability, this, in a multi-engine machine, depends on the number of engines and/or the horse-power loading of the machine. It is not commercially economical to make a twin-engine machine that can be flown quite readily by any pilot with one engine cut out. It is possible to make such a machine with three engines, and such a machine should be practically immune from forced landings due to engine failure, but as the available reliable engines are of large horse-power, it is doubtful whether the resulting aeroplane would not be larger than wanted at present or for some time. Regarding landing speed, it is obvious that the lowest possible landing speed is required, but it must be remembered that in the case of a large machine that has to be flown straight on to the ground (*i.e.*, cannot be side-slipped to lose height) reducing wing loading to reduce landing speed may produce a machine more dangerous to land than the heavily-loaded machine. It would appear that with, say, R.A.F. 15 section wings that at loading of 9.5—10 lbs. per sq. ft. gives a reasonable landing speed with a sufficiently steep angle of glide to enable a landing to be made in a confined space without spoiling the get-away and climb. The ability to make safe landings in restricted areas is governed by many other considerations than the actual speed at which the machine touches the ground, such as type of undercarriage, length of run to pull up, etc. Captain De Havilland's figures for pull-up can be bettered with considerably smaller incidence.

I certainly agree with Captain De Havilland as to wood construction. Metal construction will be used as soon as the type of construction available is worth using. Such type will be quite different from any at present developed, and it is obvious that for some years wood construction, which has not even yet reached its full development, will be used.

Regarding controls, I consider that the cable pulley has been much maligned. If the pulley is of adequate diameter, of correct section groove and properly mounted, a cable will run safely for hundreds of hours. The fairlead, however, is much more dangerous, and should be eliminated as far as possible.

W. T. REID.



NOTES ON THE STORAGE OF AIRCRAFT.

BY P. V. HOARE, A.F.R.A.E.S., A.M.I.C.E., A.C.G.I., D.I.C.

(Concluded from last month.)

HANDLING AND HOUSING AIRCRAFT.

Before storing an aircraft, it has to be housed, and this in turn gives rise to various operations of handling, in which each type of aircraft calls for particular detail. It is now proposed to consider the questions of housing and handling for each of the types of aircraft given as typical examples for storage.

As for storage, there again appears general facts which may apply equally well to all types of aircraft, and then particular treatment for each type.

With a large type of aircraft a good deal of care is necessary in handling during the process of getting it into and out of the storage shed. The difficulties then experienced will be increased in windy weather, but these may be overcome by increasing the personnel of the handling party. It is not within the scope of these notes to discuss how such a party is organised, but only to indicate the parts of the various operations which require attention to avoid damage to the aircraft. In Fig. 17 is shown a typical case of a large aircraft being hauled on the aerodrome, and in this instance a caterpillar tractor is used to tow the aircraft, while its tail is carried on a trolley.



FIG. 17.—*Handling a large Aeroplane on an Aerodrome.*

Most large aircraft of the present time are designed so that their main planes may be folded, and this is usually done when the aircraft is in store. For convenience, it is usual to fold the main planes before the aircraft enters the storage shed. It is not possible to describe in detail the folding of all large types of aircraft, so as an example that of the Handley Page 0.400 will be taken.

Assuming the aircraft is placed with its tail on a trolley, the jury struts are fitted into their respective positions between the spherical seats provided on the front spars, and each strut is adjusted in length until it is just tight. Remove top and bottom hinge pins by means of the handles provided, having first removed the locking pins. The main planes may now be allowed to swing back

gently into their folded position, and they may be steadied by means of short ropes attached to the mooring rings on the under side of the wing tips. Next place the distance pieces in position between the main planes and the fuselage. The aircraft is now in a condition suitable for movement into the storage shed.

Before taking the aircraft into the shed it is advisable, where any doubt exists, to ascertain that the roof clearances and side clearances are sufficient to accommodate the machine in the position proposed for storage. This may be done either by simply taking measurements of the overall dimensions of the aircraft and corresponding measurements of the storage shed, or by erecting a light wooden structure to indicate the overall dimensions of the aircraft, and moving this structure about inside the shed until the most suitable position for the final location of the machine has been found. In this way it is sometimes possible to obtain a more efficient distribution for storage, and the exact location of each aircraft in the shed is defined before storage is commenced, which is an advantage, as the space available for movement when the storage shed has several large machines inside is very limited.

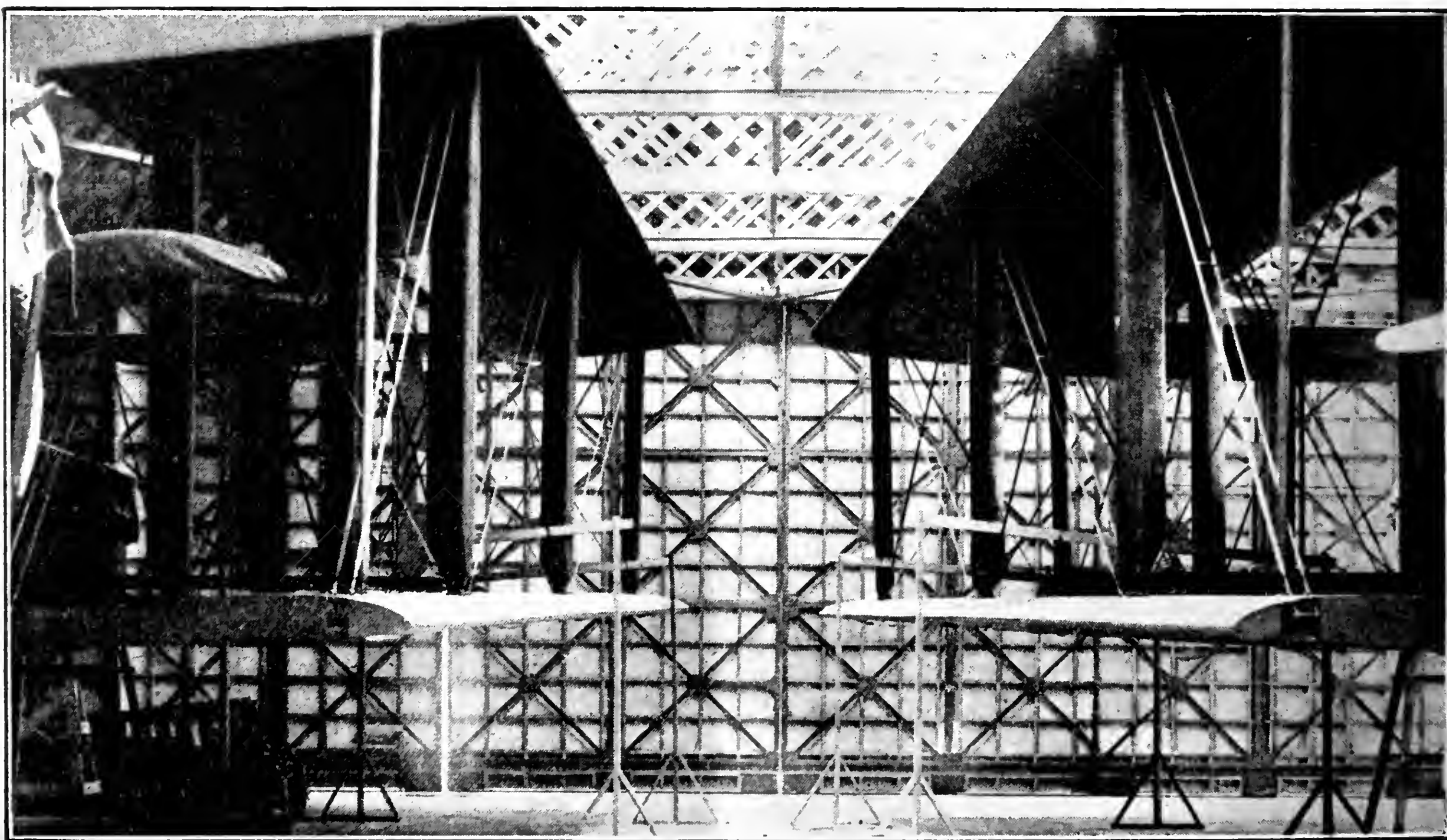


FIG. 18.—*Clearance between leading edges of Main Planes.*

The weight of a large aircraft is fairly considerable, usually several tons, and it should be remembered that when this mass is set in motion it is not easily arrested. This has bearing upon the entry of the aircraft into the shed, and where the clearances are small, the aircraft should approach the entrance of the shed very slowly, at the same time men being posted to the distant positions, such as the leading edges of the main planes when they are folded, and the top of the upper main plane, to give a signal if any part of the aircraft is likely to foul the shed; a comparatively slight bump is quite sufficient to damage a main plane almost beyond repair.

When the aircraft are in the shed freedom must be given for the movement of a particular machine either for purposes of inspection or for its removal from the shed. Such movement will therefore call for a degree of clearance between

one aircraft and another, and the magnitude of these clearances must depend upon the type of aircraft being dealt with. With low built wooden sheds the most troublesome are probably the clearances necessary between the roof of the shed and the top of the aircraft, and in some cases the roof trusses are of such design that they give less head clearance at their supports than they do at the centre of their span. Having regard to this fact, it is not expedient to leave the aircraft in such a position in the shed that if it is moved slightly forwards or backwards on its wheels it will run into a position of less clearances, *i.e.*, the aircraft should not move parallel to the roof trusses. In Fig. 18 is shown a typical clearance between the leading edges of the main planes with the aircraft folded.

As previously mentioned, various supporting devices are used for the accommodation of the aircraft in the shed, and where an aircraft of a given type has once been conveniently located it will be useful if the positions of the supporting devices are marked on the floor. For this purpose the floor may be marked with whitewash where each of the supporting devices occur, so that when another aircraft of the same type is to be stored the supports may quickly be placed in the correct positions and the aircraft moved until it registers with the supports. The correct clearances are thereby ensured and time is saved in the operation of storage.

Continuing now to the small types of aircraft.

These are sometimes fitted with folding wings, and as an example of the work involved, the detail of folding for the Fairey seaplane will be outlined.

To fold this type of aircraft the control column should first be adjusted so that the elevators are in line with the tail plane and the rudder in its central position. The quick release fittings which will be found at the following points are then disconnected:—

- (a) Main plane drag wires.
- (b) Wires from main planes to chassis.
- (c) Rear outer frame side bracing wires.
- (d) Aileron connecting cables.
- (e) Wing flap connecting cables.
- (f) Aileron cables at outer levers.

When (d), (e) and (f) are disconnected, the upper ailerons and wing flaps will be pulled upwards by their elastic return cables in the control system and the lower ailerons and wing flaps will drop down, thus reducing the chord of the main planes and allowing them to come closer to the sides of the fuselage. The jury strut between the roots of the front spars of each of the main planes is then inserted and its bracing connected; withdrawing the locking pins on the front spar end fittings allows the main planes to be swung back on their rear spar hinges. When folded, the main planes are secured by two catches placed one on each side of the bottom longerons and these catches engage with steel pins on the rear outer interplane struts. It is important that no folding should be attempted until the jury struts with their bracings have been inserted.

As discussed previously, the operations of placing small aircraft in the storage shed do not present so many difficulties as the larger types, their lightness and smaller form admitting of more freedom in handling. Care is necessary, however, particularly with the wing tips, as in cases where the wings do not fold, and men should be posted, one at each wing tip, while a machine is entering the shed. It will be found convenient to locate the smaller types of aircraft in positions head to tail alternately along the shed, but not so close as to allow the main planes of one aircraft to foul the tail unit of the adjacent one. The general idea of such a layout can be seen by referring to Fig. 12, where the aircraft concerned are of the Sopwith Snipe class. As before, the positions of the supporting trestles and packing blocks for the undercarriage may be marked in whitewash on the floor of the shed, and a clearance zone similarly outlined

round each machine to prevent persons from walking into parts of the external bracing, such as drag cables from the front of the fuselage to the outer interplane struts.

The manipulation of boat and float seaplanes, so far as movements into and out of the shed are concerned, is similar to that employed for aeroplanes. The inability of the aircraft to travel over the ground is overcome by placing it on a suitable cradle, or trolley, designed to meet the particular needs of the aircraft. When the seaplane is in position on its cradle or trolley it may be regarded for handling purposes as an aeroplane. The trolley for a float seaplane and the cradle for a boat seaplane have been previously described.

In addition to the clearances which have been outlined above and are necessary for the safe movement of a particular machine within the shed, it is also necessary to have unrestricted access to most parts of the shed in case of fire. The most important factor in this is a clear floor space, and when aircraft have been correctly supported and stored in the shed, all unnecessary loose objects should be removed. Reference to Fig. 18 gives an idea of what is required in this direction, although in this illustration no fire extinguishers are shown. In practice, fire extinguishers should be located at several accessible points in the shed, and an adequate supply of sand should be available to work in conjunction with the fire extinguishers. In the case of collective storage of aircraft a clear floor space is not possible, but gangways between the various machines should be kept quite clear. In Fig. 12 an arrangement for fire extinguishers is shown, but no hard-and-fast rule can be laid down with respect to this matter, it being based only upon the circumstances of each particular shed. A convenient allotment of fire appliances is one extinguisher per 1,000 square feet and one bucket per 2,000 square feet of floor space. The buckets may be used for either sand or water as desired.

COMPONENTS.

In considering the storage of component parts of aircraft it is intended only to deal with the sub-divisions which occur in general use and not with detailed dismantling, such as the dismembering of a fuselage into its struts and longerons. For prolonged storage, aircraft may be accommodated in a much smaller space when they are separated in components, but it follows that the subsequent erection must necessarily take longer. One or two fundamental principles should be borne in mind in this matter, the chief being that when an aircraft is dismantled it is always advisable for the components to retain their association with each other. Therefore a system of distinctive labelling should be formulated as a means of identification of the various parts and to ensure that a particular aircraft is re-erected from the correct components. In this way many minor details of fitting will be avoided, as although the various parts are designed to be interchangeable, yet when reduced to detail, matters such as the fitting of locking pins in their holes may be facilitated by knowing that a particular pin will, without alteration, fit correctly. Further, with the aircraft in the dismantled condition, the components are more easily handled and there should be less liability for damage to occur than when the complete aircraft is handled as a unit.

It is proposed now to sub-divide the aircraft under the headings of its components.

Fuselages.

In the case of a small aircraft the fuselage is usually considered as a single component and may be either of wood or metal; in the former there is a possibility of dismembering the parts, whereas in the steel variety, the individual members are usually inseparably attached to one another. The possible methods

of storage for the wooden fuselage are therefore greater than the steel ones, but as mentioned previously, the sub-division of the components is rarely carried out.

Fuselages of large aircraft are mostly designed so that they may be split into sections, an example of which occurs in the case of the D.H.10 aeroplane, where there are the front, middle and rear portions, each of which can be considered as a component and their detachment from each other readily carried out. It will be convenient, therefore, to regard the sections of a large fuselage on the same lines as the complete fuselage of a small aircraft.

Fuselages are necessarily long and comparatively narrow structures, and whether of wood or metal they are subject to deformation under loading, which movement may in time become a permanent change of shape and of such magnitude as to render the components unfit for further use. This fact calls for the adequate supporting and simply to support fuselages at each end will not usually suffice. Provision must be made to prevent sagging, and the best way to overcome this is to arrange several supports throughout the entire length of the fuselage and to place these supports under cross bays of the structure. Sagging is a particular tendency of built-up members, such as those of McGruer construction, and fuselages embodying this principle should be supported at many points throughout their length. The supporting points, too, should be arranged so that they each carry their particular share of the load, as one high point, in a system of supports, is as detrimental as a lack of support at that particular place.

With these conditions borne in mind, the fuselages or sections of fuselages may be placed horizontally and stored either singly or one above the other according to their weight, thus the complete fuselage of a Handley Page aeroplane would be stored singly, as to place one above the other would involve too much load falling upon the lower one, in addition to the great difficulty which would be experienced in placing them in position in storage sheds not having overhead gantrys. For the same reasons it is not expedient to store more than three small fuselages one above the other.

The weight on the lower fuselage could, of course, be relieved by constructing racks which carry each fuselage independently, but the difficulties of placing the upper ones in position and of carrying out satisfactorily the periodical inspections more than outweigh the advantages which may accrue from rack storage. A typical method of supporting large fuselages from the floor of the shed is shown in Fig. 19.

To avoid damage by the supporting members, the loads should be carried on pieces of felt or other soft material, and in cases where longitudinal members are supported in an inclined position, wedge-shape packing should be arranged on the supports so that the member is not bearing on the edge of a trestle.

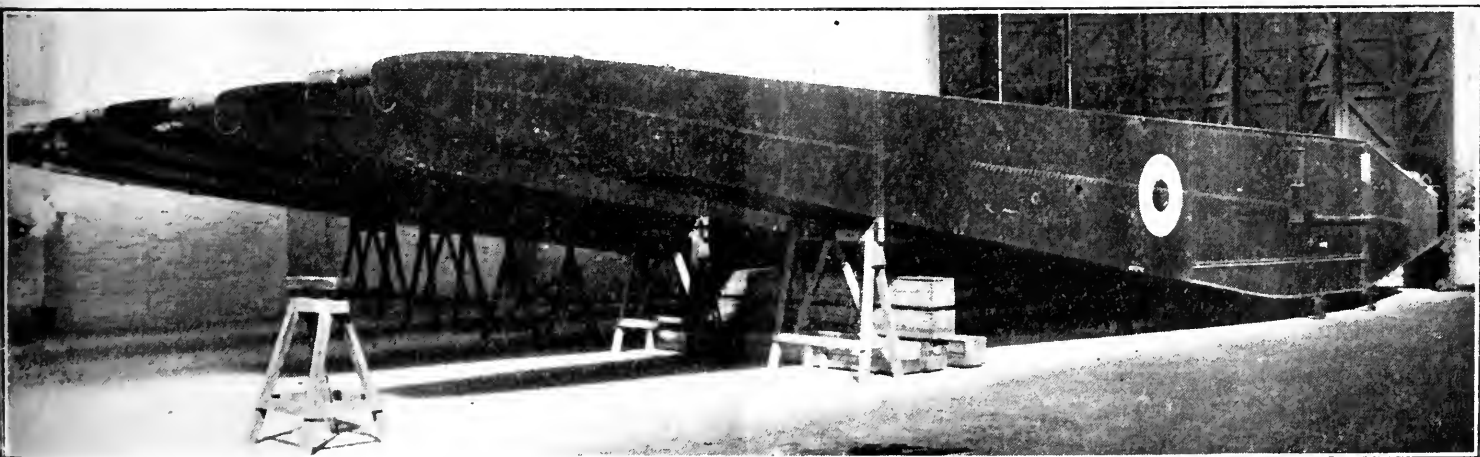


FIG. 19.—*Handley Page O/400 Fuselages in Store.*

The actual dimensions of supporting trestles or racks need not be defined, but if timberings of substantial size are used so that the supports can carry a large fuselage, these same supports may be used, suitably spaced, to carry smaller fuselages, thereby reducing the number of different types of trestles which have to be constructed.

In cases where fuselages have their fabric coverings laced on, it is better to remove these coverings so that periodical inspection of the structure may be easily carried out. If the entire fabric cannot be conveniently removed, such portions as are laced in position should be taken away. The metal fittings of the fuselage should be treated to prevent corrosion by being first cleaned down and any traces of rust removed, and afterwards coated with a suitable grease compound to exclude air from the entire fitting. The grease should be evenly and thoroughly applied to prevent corrosion from commencing and extending under the grease film. In applying this protective coating, care should be taken to prevent it from being placed on fabric, as the constituents of the grease have a deleterious effect on the dope film. The metal bracing wires of the structure should be similarly coated. In cases where a large fuselage has been separated into its several components, any bare end grain of timber should be varnished over.

Hulls.

Seaplane hulls may be regarded as analogous to fuselages of large aeroplanes, but unlike these, they are usually not separable into components and so cannot be subject to the conditions of intensive storage. Their shape also does not lend itself to such simple methods of supporting as are employed for a rectangular fuselage. A hull stripped of all its fittings can be accommodated either in a cradle or on specially constructed trestles, and although these components are of more rigid construction than fuselages and not so liable to sag or distort, yet to retain their efficiency they must be maintained watertight. The main points in their storage are therefore suitable supports and an adequate means to prevent the hull from becoming leaky.

Dealing with the question of supports, the easiest and probably most convenient method is to employ a mobile trolley, similar to that used for the complete aircraft, and where a sufficient number of these trolleys are available the hulls may safely be placed upon them and left thus supported in the desired positions in the storage shed. If the hull is likely to remain in store for some time it is advisable to pack up the bow and stern on trestles to prevent sagging of these overhanging portions. The supporting surfaces of the trolleys consist of cross battens which are spaced about 2in. apart, thus allowing free access of air to the underside of the hull.

A trolley is shown in Fig. 11 and may be used either for beach work or for storage of the hull. As an alternative to this cradle, the hull may be supported on three cradle trestles as shown in Fig. 20, and these will be found convenient where mobile trolleys cannot be spared for storage work. These cradle trestles are placed, one under the edge of the front step, another about 6in. aft of the main spar attachments, and the third under the tail end near the tail plane strut attachments, thus leaving the entire bottom of the hull exposed. They are constructed of heavy timberings with their bearing surfaces about 12in. wide and heavily padded to prevent injury to the hull. In front view they are V-shape, and the apex of this "V" is cut away to give clearance for the keel; these supports are strong enough to carry the complete aircraft if necessary.

There may appear a little difficulty in placing hulls on these trestles, and in the operation of moving the hull from the trolley to these trestles the tail is first pulled down so as to raise the front portion just clear of the trolley; and in this position the front trestle is placed under the hull and close to the

trolley. The hull is then lowered on to the front trestle. By raising the tail on the front trestle the trolley can be run clear and the centre trestle placed in position just aft of the rear spars and the hull lowered on to both trestles. This operation can be carried out either by man-handling the hull or by lifting from an overhead gantry where such exists. Owing to the weight of the hull and the size of the supports, it is not possible to adopt any method of rack storage as used for certain fuselages.

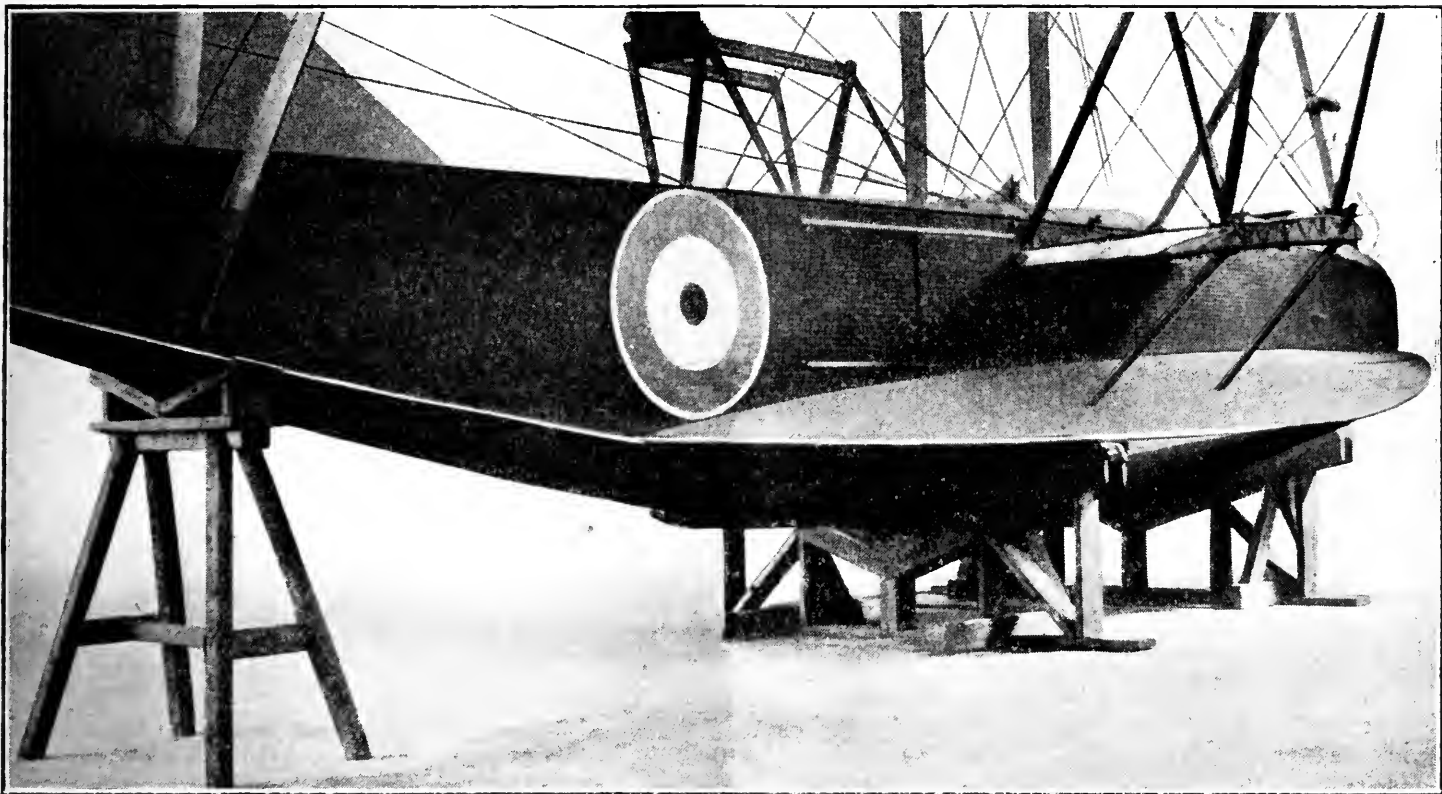


FIG. 20.—*Seaplane Hull on Cradle Trestles.*

To prevent shrinkage of hulls certain methods are adopted, one of which has been previously outlined. To this end also hulls may be washed down periodically with fresh water at times, dependent largely upon the weather; but as often as is necessary to keep the hulls damp. In this case drain plugs should be kept open until the hulls are wanted. Another method of maintaining the hulls watertight is to close the drain plugs and place a quantity of fresh water inside each hull and allow it to remain there during storage. This water should be changed at intervals. When this method is used the weight of the water used must be borne in mind when arranging the supports for the hull. If during storage the planking shows signs of shrinkage a coating of thin varnish should be applied, the joints having been previously filled with white lead. After a hull has been cleaned down and made watertight, dust and dirt may be excluded by fitting a cover over the whole structure. This cover should be readily detachable to facilitate the periodical operations on the hull. All metal fittings which are permanently attached to the hull should be carefully avoided when the water treatment is applied and before storage is commenced they should be properly cleaned and coated with grease or painted.

When stored in sheds which are heated during the winter, hulls must be kept clear of all heating appliances and in sheds of corrugated iron they should be placed at least four feet from the sides of the shed. It is also advisable to prevent direct access of sunlight to the hulls.

Main Planes.

In dealing with the storage of main planes it is proposed to consider these components as separate units, with the centre section planes excluded, and with the ailerons (and wing flaps in the case of the Fairey seaplane) removed. In general, these components are more convenient to store than fuselages, but their frailty calls for careful handling, which in turn is rendered more difficult by their size.

There are three possible ways to store a main plane, namely, resting on its leading edge with its chord vertical, lying with its spars and chord horizontal, or resting on its spar ends with the spars vertical.

These methods have been enumerated in the order of preference, having regard to convenience of storage and liability to damage. With the first two methods the space required for accommodating planes will be governed by the length of the shed, while the third method necessarily calls for roof clearance; it may be added too, that in the case of a main plane of a large span, storage by the third method becomes impracticable owing to the difficulties in handling the component. This method may, however, be used for main planes of small aircraft.

Taking firstly storage with the leading edge horizontal and the chord vertical. The general factors entering into this case are, that the leading edge of a main plane is very fragile, and again, a considerable area of taut fabric is exposed to damage from the side. It is therefore not advisable to carry the whole weight of the main plane on one or two points of support under the leading edge, as a small lack of adjustment of these supports or the interchanging of one type of main plane for another on the supports, would probably entail damage to the leading edge. The fabric surface is most liable to damage by the fittings for the main plane bracing wires, which project slightly from the surface of the plane, so that each plane should be carefully confined by adjustable clips to prevent it from rolling over on its leading edge. The supports for the leading edge should preferably extend throughout its whole length, and because the plane is slid into its position in the rack, these supports must be felt covered and free from any projections. In Fig. 21 is shown a main plane storage rack, which conforms to the above conditions. In this instance, the planes are supported on planks which are raised just clear of the floor and are covered with felt. The rack is divided into bays, each of which accommodates one pair of planes, so that the association of the planes for a particular aircraft may easily be maintained. To prevent one plane from rolling against another, adjustable "V" shaped packings are placed over each trailing edge, and the planes are arranged with the lower surfaces of each pair facing one another. Racks of this description may be used to store several different types of planes, and the upper portions of the racks may be used for other purposes.

It is obvious that these racks must not completely fill the storage shed, as clearance is necessary for placing the planes in position; they can, however, be placed so that they face the doors of the shed, in which case the planes may be entered or removed by opening the shed doors, thereby obtaining the necessary clearance. Their actual location in the shed will therefore be determined by the design of shed, but where possible they should not be backed on to a blank wall, as this conduces to an accumulation of dirt between the wall and the rack and a tendency to harbour vermin, both of which are undesirable and can only be removed by emptying the entire bank of racks.

The second method of storage, that is, with the main planes lying flat and their spars horizontal, introduces many of the features of the previous method, but in this case the storage racks are horizontal, and the weight of the plane normally rests on the spars, which, being strong members, need not be supported

throughout their entire length. Now this is easily done with planes of a flat aerofoil section, but when dealing with those of the high lift variety, that is, of considerable camber, they would, if placed on the flat surface of the rack, rest only on their leading and trailing edges. The rack therefore must either be cut away to allow these edges to overhang, or with the rack of width equal to the length of wing chord, the supports for the spars must be raised above the level of the rack. In placing the planes in position, the projecting parts of the main plane fittings do not allow the planes to be slid in position. These projections must be lifted clear of the supports, and the work involved, therefore, is slightly greater than with the former method, as a particular plane has to be lifted at both ends and then lowered on to the rack. The supporting members of the racks should be felt-covered. With this method of storage the planes are racked separately, which increases the storage space required as compared with the previous method. The height to which planes may be stored in this way is

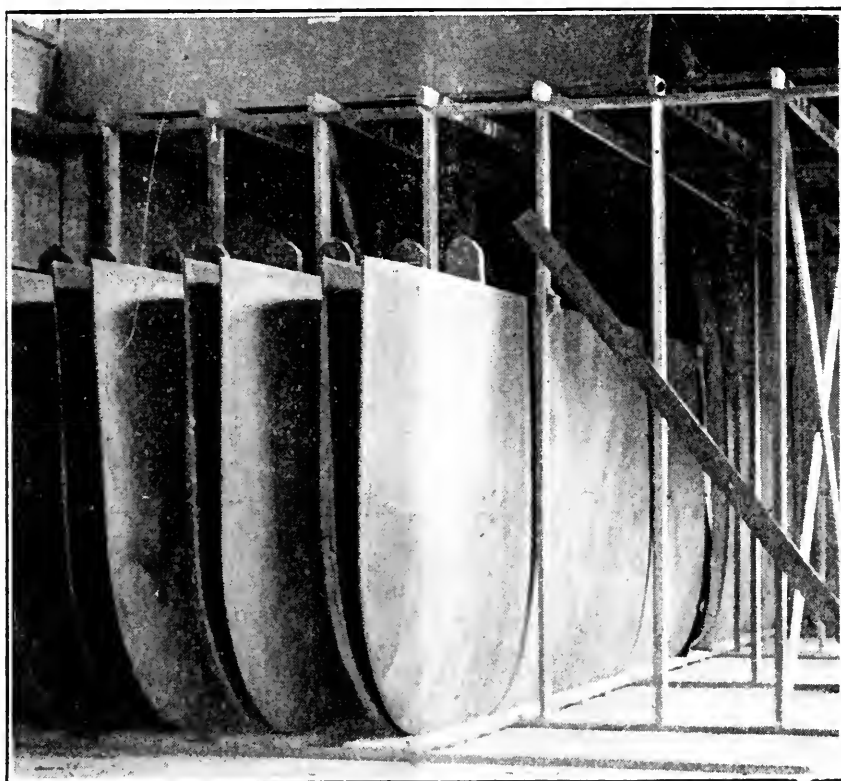


FIG. 21.—Main Planes stored on leading edges.

governed by the accessibility of the racks, but in practice, difficulties will be experienced in taking them higher than the reach of an average man. Each plane should be distinctively labelled to show to which aircraft it normally belongs.

The other alternative method of storage is with the spars of the plane vertical, and is practically limited in use to planes of not more than 15ft. span. In this case the load is carried on the ends of the spars and end rib, supports being arranged slightly raised from the floor and so that they lie under the ends of the spars. Provision must also be made to prevent one plane from rolling into another. In Fig. 22 are shown planes stored in this position, and in this case, each plane has its separate compartment defined by cross battens at the top of a rack. The battens may be substituted by strips of webbing if desired, but the former is preferable, as the webbing is liable to break, and is really only used in the absence of better material. The main planes in this instance are shown with their ailerons attached, but they may be accommodated in a much smaller space by removing the ailerons, which dispenses with the projecting

aileron levers. In sheds where sufficient head room is available, this method probably leads to more compact storage than the previous ones, and not such a large horizontal clearance is required for placing the planes in the racks. In large storage sheds it will be found convenient to place this type of main plane rack round the walls of the shed, as the back of the rack may easily be seen and is accessible for cleaning purposes.

Control Surfaces.

For purposes of this section the control surfaces will be considered as comprising the tail plane, fin, rudder, elevators, ailerons, and wing flaps.

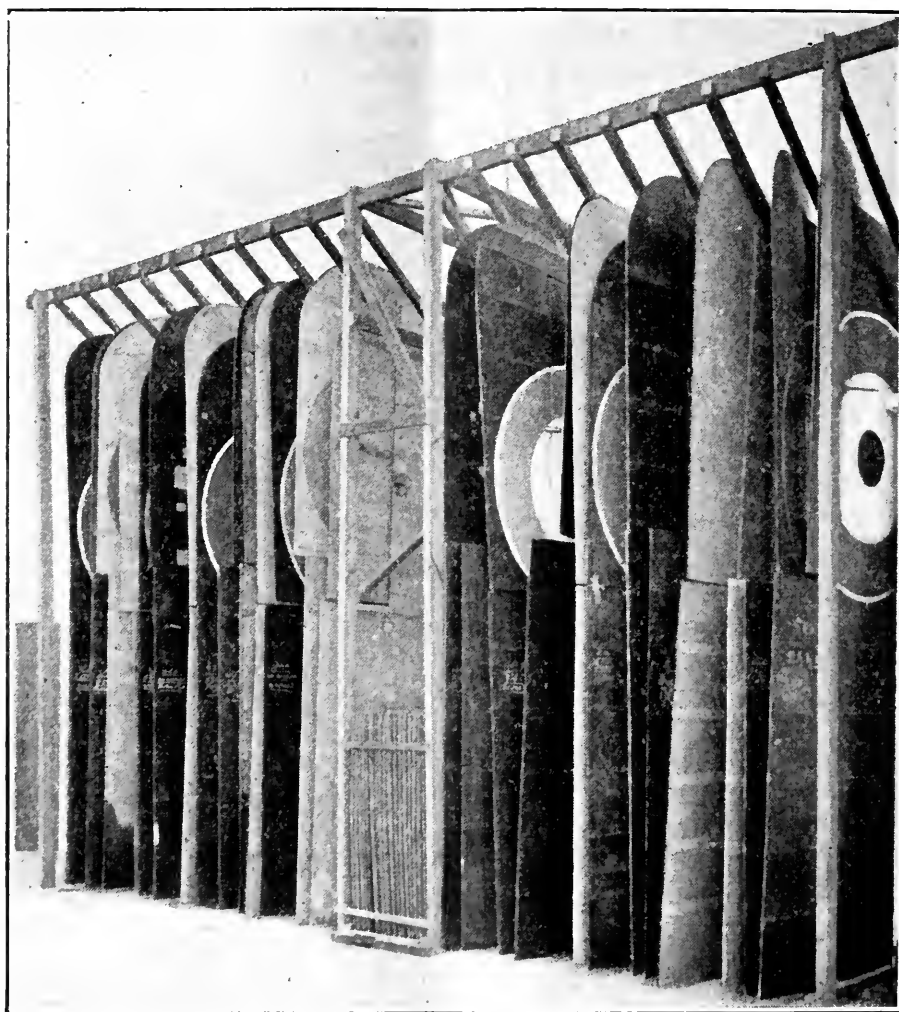


FIG. 22.—Main Planes stored on end with batten partitions on rack.

Except for large aircraft, all these components are of comparatively small dimensions and are easily handled; further, their lightness reduces the tendency to sagging and permanent deformation such as is found with the larger components. The small size of these components also permits their being accommodated in any convenient space in the storage shed, and usually without any special design of rack. Where main planes are stored with their spars horizontal, these smaller components may be placed on the top of the plane racks, arrangements being made for the parts to maintain their association with one another, either by a system of labelling or by placing together a whole set common to one aircraft. It should be remembered that these parts have the inherent frailty of the larger surfaces, and damage may easily occur through careless handling. The elevators, rudders and ailerons have rigidly attached levers which project

nine or ten inches at right angles to the fabric surface, consequently a clearance for these projections has to be allowed when calculating the storage space required, and when placing one surface against another. When it is likely that these parts will continue in store for some time, these levers may, at the expense of the fabric, be removed so that the surfaces may be packed together in a much smaller space, but this practice cannot be recommended where a quick erection of an aircraft may be called for. The tail planes and fins are usually free from such encumbrances and afford better facilities for the complete storage. No particular arrangement need be formulated, but it is preferable that the parts should be placed resting on their edges. With tail planes, which are adjustable in flight, certain parts of mechanism are integral with the structure, and the metal of these parts must be adequately protected during storage. The same thing applies to all the metal fittings, such as the levers previously referred to, and the treatment previously outlined for the metal parts of fuselages may be used in these cases. The tail planes of the larger types of aircraft may, on account of their size, be accommodated in racks similar to those used for the main planes of smaller aircraft.

Undercarriages and Chassis.

In a large number of cases the undercarriage or chassis remains attached to the fuselage to act as a support for it, but where this is not done, the component, usually being a non-rigid structure by itself, may be dismantled into its main parts. The undercarriage for an aeroplane may be sub-divided into the supporting struts and axle with, of course, the wheels removed. In this way it may be stored in a compact manner.

The simpler types of undercarriages consist of two sets of "V" struts connected to the axle through shock absorber elastic, and when this structure is dismantled the side struts may be packed separately with their respective fairings, and the axle with its fairings placed with these struts. The majority of undercarriages are constructed principally of steel, wood only being incorporated in so far as it is required for purposes of fairing. The requirements of storage of steel parts must therefore be met for the exposed metal portions, but the fairing gives partial protection to those parts which it covers. Particular attention should be given to mechanical shock absorbers such as is used in the Oleo type of landing gear. In these cases the simpler "V" construction is substituted by a more complicated mechanical contrivance, the mechanism of which calls for treatment. The guides for the shock absorbing springs must be carefully cleaned, together with the springs themselves, and all the working parts of the unit well oiled and finally coated with anti-rust preparation. In the matter of wheels and tyres these may be regarded as interchangeable parts to the extent that the provisions previously advocated to maintain the association of the part of an aircraft need not be rigidly carried out. All wheels of one size may be grouped together and stored, preferably on vertical spindles, or alternatively on horizontal spindles, with the tyres clear of the ground. The normal air pressure in the tyre of about 50lb. per square inch should be released, in this way avoiding fatigue to the rubber by relieving the tyre of surface tension. Whether tyres are removed from the wheels will depend a good deal upon the likely demand for the wheels. If, however, the wheels are to be stored for a considerable time, it is better to remove the tyres, as any rusting round the rim of the wheel where the tyre is in contact will cause depreciation of the rubber. With the tyres removed the fabric fairing covers on the wheels may also be taken off, and the spokes and hub cleaned and greased; particular care should be given to the internal portion of the hub to prevent the rusting.

After shock absorber elastic has been in use for some time it is questionable whether this material can again be utilised with efficiency. To render this a

possibility, however, it should be coiled and stored away under similar conditions as for tyres, that is in a place where the temperature is maintained fairly even, and where it will be quite free from oil.

If a complete undercarriage is likely to be required quickly from store, it may, after being removed from the aircraft, be kept in its complete condition by constructing a light framework which will anchor together the tops of the struts, and so complete the rigidity of the framework in the same way as when it is on the aircraft. In this way it will not be so convenient a component to store, but it is easily rendered available for use by removing the retaining framework from the tops of the struts, when it is ready to go straight on to the aircraft. It is hardly necessary to add that the bracing wires will, in most cases, have to be disconnected, and where the undercarriage is stored in parts, the bracing wires will be dealt with separately, as described later.

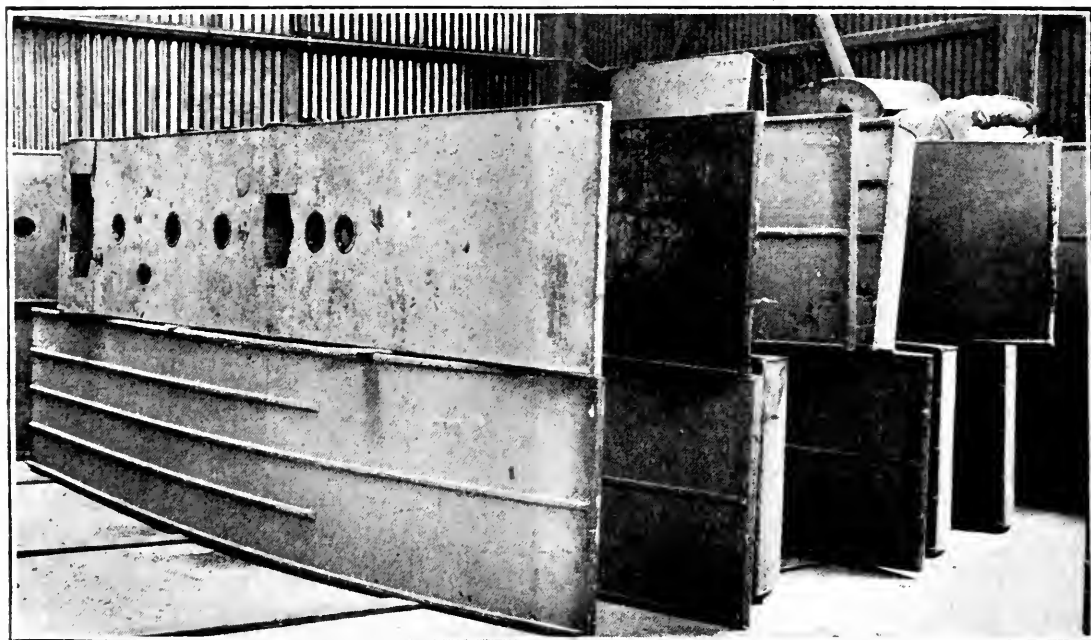


FIG. 23.—*Seaplane Floats in Store showing inspection covers removed.*

Considering the corresponding unit, as used on a seaplane, which for distinction is usually called the chassis, the make up of this component is constructively similar to an undercarriage in that it is a braced structure attached one end to the aircraft and having floats at its other end. Taking this component as a whole, the chief differences of treatment as compared with an undercarriage will be due to the effects of sea water, and to the frailty of the floats.

When the chassis is dismantled, the struts and bracing wires may be arranged similarly to those of an undercarriage, but the floats call for special comment. In storing these parts they can be arranged one above the other, resting either on their sides or on their bulkheads; for convenience in storing the former is preferable, as it gives a flat surface on which the float can rest, and on which battens may be placed for the support of the upper floats. In either case a space should be left all round each float for the free circulation of air, and the distance apart of each pile of floats should be at least one foot. During the time that floats are in store all the inspection covers should be opened up to give free access of air to the interior. The floats should be cleaned down before being placed in position in the storage shed, and all surplus water and dirt removed. Where three-ply construction is used, water must not be placed in the floats as it affects the glueing of

laminations and may cause buckling. The supports for these parts may conveniently be 3in. by 3in. quartering, which is laid in the first instance directly on the floor. The first set of floats rests on these supports, then further similar supports are laid along the top of these floats and a second tier placed over the first; it is not advisable to place more than two floats one above the other. Floats stored in this manner are shown in Fig. 23, in which they are arranged resting upon their sides and two deep upon the floor of the shed. All the precautions necessary for the satisfactory storage of thin timber and glued joints should be observed, the conditions of temperature and humidity of air being the chief factors.

Wing Tip and Tail Floats.

These floats are of lighter construction than main floats, and therefore fall to be dealt with by similar treatment. They should not be allowed to rest upon the floor, but may be either suspended or laid on quartering as detailed for main floats. In some instances it will be found convenient to accommodate them over the main plane racks with the control surfaces of the aircraft. In most cases strut bracing is attached to these floats, but its removal is not absolutely necessary owing to the small size of the unit. Care should be taken to see that the struts of one float are not placed so that they may penetrate the adjacent float, the fabric side coverings sometimes used being very easily damaged.

Bracing Wires and Cables.

Most of the external bracing of aircraft is now in the form of streamline wires, but cables are also used for such purposes as the bracing of the chassis of a seaplane. When an aircraft is dismantled for storage these bracing wires are detached and have, of course, to be stored in common with the rest of the aircraft.

For ease of subsequent erection of the aircraft it is essential to know to which part of the machine a particular wire or cable belongs, as in some cases the lengths may differ only very slightly and trouble will occur by trying to fit a wire of slightly incorrect length. The labelling of these parts, therefore, should be carefully done, as the location of a particular wire is sometimes not so obvious as that of a component such as a main plane. The system of identification of wires by brass tabs may conveniently be used to supplement the collective labelling. In cases of streamline wires, their shape enables them to bend easily in one direction, but undue bending may produce a permanent set which it is difficult to remove without injuring the wire. For this reason, when the wires are bunched up together, it is not sufficient to support them in a few places, but they should be laid on planking extending throughout their entire length. Each wire should, before storage, be treated by cleaning down and coating with a suitable anti-rust preparation, which should be applied thinly and evenly over the whole wire, and each wire be allowed to remain separate until a hard coating has been formed. When all the wires which it is required to group together have been so treated they may be bunched up, tied, and placed in store. It has been found that the surface developed by certain anti-rust compositions eventually becomes brittle, and the composition is liable to flake off, so that once a bunch of wires have been stored they should not be disturbed except for purposes of inspection and re-coating. Other protective means have from time to time been devised, and later it is possible that galvanising or sherardising may be employed.

Flexible steel cables have need for the same protection from corrosion as streamline wires, but as they are not so liable to take permanent set by moderate distortion there is no need to support them throughout their entire length. In

the cases of the smaller cables, however, there is a tendency to kink if they are badly coiled, and once a cable has developed a kink its efficiency is practically destroyed. In the process of storing these cables the opportunity should be taken to see that there are no frayed parts and that splices are in good condition.

Engines.

In dealing with the storage of engines as separate units, it is not proposed to enter into the detail matters of dismantling and overhaul, even though such operations may, in general, be desirable. The engines will be considered as units calling for special attention to the precautions for storing metal parts; only the mechanical parts will be dealt with and such accessories as oil and fuel tanks with their pipe systems will be omitted.

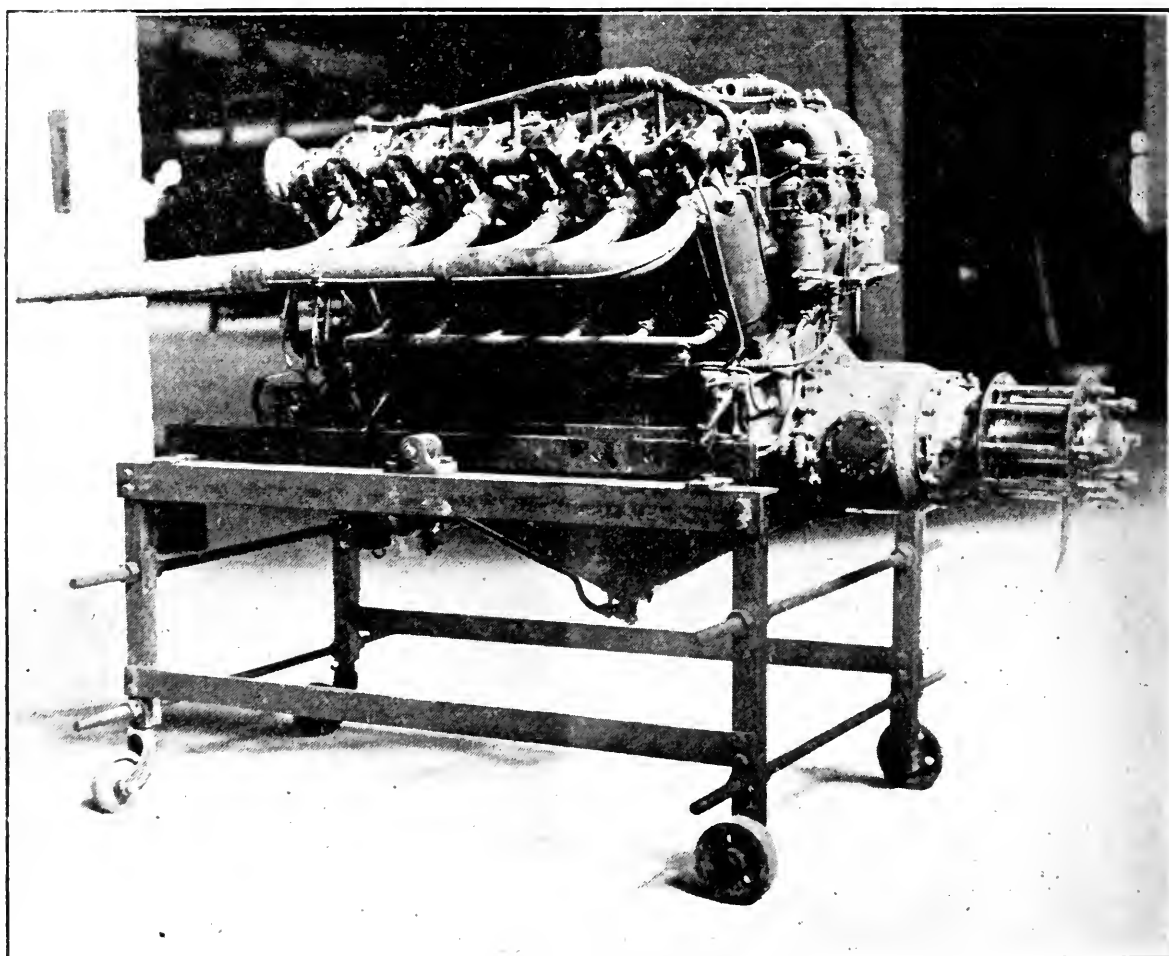


FIG. 24.—*Engine on Mobile Storage Cradle.*

In general, engines should be stored in a dry place, and may be accommodated on suitable cradles, preferably of the mobile type, so that if it is desired to obtain access to a particular engine for purposes of inspection this engine can be moved from its storage position into a more convenient place for carrying out the work. Each type of engine will necessarily call for a modification in the design of storage stand, but by constructing stands of sufficient width and length to accommodate the larger engines, they may also be used for the smaller types. A typical engine may be taken as the Rolls-Royce Eagle VIII., and in Fig. 24 an engine of this type is shown resting on a mobile cradle; the cradle in this instance being of steel construction, but a wooden cradle would serve the purpose equally well. It is essential that the engine be supported throughout its length as local loading causes stressing of the crankcase. The engine will normally

come into store as taken from the aircraft, and will contain some oil and possibly some water in its cylinder jackets. This oil and water must be removed from the engine, the removal of castor oil being very important on account of the property of this oil in absorbing water, and so causing corrosion of the metal parts with which it is in contact. It is next advisable to check over the external parts of the engine to see that they are all in position, after which the outside of the engine should be cleaned down and coated with an anti-rust preparation. It is an advantage to remove the carburettors and to clean these parts separately, afterwards replacing them on the engine. The plugs and magnetos may also be removed and stored as instruments, the holes of the former being closed by wooden pegs and those of the latter covered with fabric. Where the engine has been disconnected from its service system, the open pipes or unions must be closed to prevent the entry of dirt. For this purpose fabric covers can be cut out and tied in position over the various openings.

In the cases of rotary and radial engines the tappet rods should be disconnected and secured to the engine.

Before putting the engine away a small quantity of high grade thin oil should be poured into each cylinder, and squirted into the interior of the engine through the breathers, or—in the case of rotary engines—the crankshaft, and also into the gears where such are fitted. By turning the engine a few times, this new oil can be sufficiently distributed to form a film over the interior of the engine.

When the engine is located in a desired position in the storage shed it can be completely covered by fabric tied in position, but in attaching the fabric cover it must be remembered that periodically the engines are turned, and the attachment of a cover to the propeller boss and other moving parts should be arranged accordingly.

All loose external parts which belong to the engine should be removed, separately packed, and placed with the engine.

Air screws.

Most existing air screws are of wooden construction. They are sometimes fitted with metal tips or a metal sheath extending partly up the blade, and in a few instances they are of all-metal construction. The storage, however, will concern chiefly the wooden variety. The design and construction of the average air screw makes it inherently liable to change of shape, and to trouble with its glued joints. Once joints have given way there is no remedy, and the air screw has to be written off as unserviceable. The prime factor, therefore, in the conditions of storage of these parts is the temperature and humidity of the air, but further than this, as glue is an uncertain compound in its behaviour, it is necessary to have free movement of the air screw when stored in a vertical position, and to overcome the vagaries of the glued joints and timber in laminated form, the air screw has periodically to be turned.

In Figs. 25 and 26 are shown two methods of storage—in the first case for a four-bladed air screw, and in the second, for a two-bladed air screw. In the former, the air screw is mounted vertically on a peg against the wall, and may occupy any convenient space in the storage shed, provided that it is not placed immediately over a radiator or in the vicinity of air currents of changing temperatures. As the wall of the building is liable to be coated with a deposit of dew under suitable atmospheric conditions, it is essential that the air screw must have two or three inches clearance, and this may be ensured by placing short battens between the boss of the air screw and the wall.

In the other method the disadvantages of placing the air screws against a wall are overcome by having them on a rack. This rack is of simple design, and

constructed of substantial timberings with suitable pins projecting through its upper rail to carry the airscrews. Each pin is capable of accommodating two airscrews on each side of the rack. In this position the airscrews cannot be rotated as required, but similar effect may be obtained by removing a particular airscrew, turning it end for end, and replacing it on the rack.

It is a point to note that a rack of this description containing airscrews should not be placed where it will be exposed to the wind if the shed door be opened, as the effect of this may be to rotate the airscrews with sufficient violence to cause one airscrew blade to damage the edge of the next one.

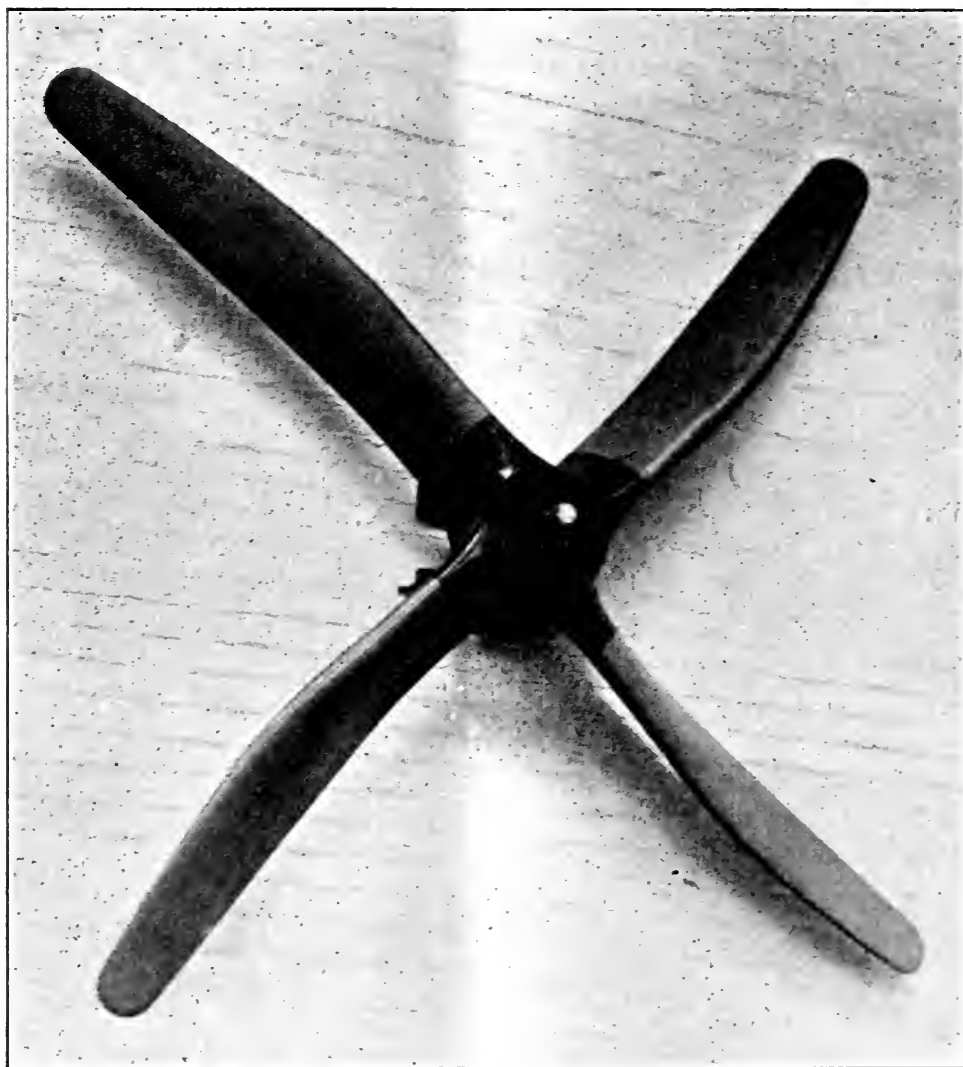


FIG. 25.—*Airscrew stored on Wall Peg.*

Another method which may be adopted is to place the airscrews in their packing cases, where such cases are available, and to stack the cases flat one above the other. Airscrews which are already packed may be accommodated in this way and need not be removed from their cases for storage by the previous method.

When airscrews are brought into store after being in flight they should be wiped down and any defects in the varnish made good before they are placed in store. In a similar way the fabric or metal sheaths, where such are used, should be inspected and any damaged places repaired.

In all cases the metal boss is removed from the airscrew prior to storage and either goes with the engine or is stored separately.

Instruments and Accessories.

The parts falling into this category are chiefly air speed indicators, revolution indicators, thermometers, compasses, pressure gauges and the like, added to which may be some of the intimate parts of engines such as magnetos. It should be borne in mind that these parts are costly, so that care must be taken to prevent losses while in store. At the same time it is necessary to guard against damage by seeing that they are carefully handled.

The fitting of these instruments usually does not call for so much detail as the constructional features of the aircraft, so that the same degree of association of these parts is not so necessary as say for main planes and tail planes, although for compasses and magnetos which have been set with respect to a particular aircraft or engine it is an advantage to have their exact location designated. It is a convenience, also, to have each instrument labelled with the designation of the aircraft into which it is normally fitted, but this information is of use primarily as a check upon the number of instruments, and apart from the exceptions given above it is not intended that the instruments should necessarily be replaced in the same aircraft. Having regard, therefore, to the above conditions it will be appreciated that a detailed clerical record is required for the successful storage of instruments, and these records should show the identification numbers of each instrument and particulars as to location in the store, together with identifying particulars of the aircraft from which they have been removed. These parts do not call for any special rack for their accommodation and they may be placed in bins, preferably of sheet steel.

It is sometimes recommended that instruments be tested before being placed in store, but in any case it is not expedient to place an instrument in use immediately after it has been stored for some time, without testing it prior to fitting. The components of some instruments are very susceptible to changes of temperature, and those which contain the rubber parts may, of course, depreciate through perishing of the rubber. It is advisable, therefore, that the building in which instruments are to be stored should be capable of being maintained at a constant temperature, and where possible, at a constant humidity. This purpose is best served by choosing a small building as an instrument store in which the atmospheric conditions may more easily be controlled.

Instruments containing mechanical mechanism should be protected internally from corrosion by the judicious injection of thin high grade oil.

Revolution Indicators.—Revolution indicators of the centrifugal type should have their mechanism covered with thin oil before being placed in store. The electric type of indicator must not be oiled and should be placed in a damp-proof compartment. It is an advantage to cover the open end of the connection for the flexible cable to prevent moisture from entering and damaging the interior of the instrument.

Both these types of indicators are operated by a flexible drive which consists of a rotating core within a flexible sheath. The outer sheath should be cleaned down and greased, while the flexible shaft should be removed and be liberally coated with grease before being replaced within the sheath.

Transmitting Radiator Thermometers.—The most important part of these instruments is the pipe connection between the indicator and the thermometer bulb. The whole system is hermetically sealed and when handling the instrument for storage purposes great care is needed to ensure that the pipe line does not become cracked through being faultily coiled, and that any joint in the system is not opened; the pipe line is fairly flexible material, but undue advantage must not be taken of this property to effect its storage in a very small space. The operating liquid is usually a volatile compound and easily affected by changes of temperature, and so as not to subject the indicator to continual loading, the place in

which these instruments are stored should have an even and not too high a temperature.

Air Speed Indicators.—These instruments depend for their operation on the functions of a hermetically sealed chamber, and the ends of the leading-in pipes should be capped off. Accompanying an air speed indicator will be a pressure head, and as the small holes in the static side must be kept clear, the storage bins or racks should be wiped out to remove dirt and dust before these instruments are placed in position. It is also necessary to avoid burring the edge of the pitôt tube, which in effect will alter the coefficient of the pressure head and the calibration of the indicator.

Compasses.—Compasses, with the card locked, should not be stored in the vicinity of a strong magnetic field. The instruments should be laid horizontally and after the compass has been placed in position the card should, where possible, firstly be freed and then locked when it has settled down. The same method of storage should be adopted for both liquid and dry types of compasses. As mentioned previously, for re-setting purposes, it is advantageous to indicate to which aircraft each particular compass belongs and its exact location in the aircraft.

Magnetos.—After removal from the engine each magneto should be cleaned down and oiled, avoiding any excess of oil and ensuring that no oil enters the electrical system; it should then be tested and if satisfactory be placed in store. Differing slightly from the principles of storage for the former instruments, these are arranged one only in each compartment of the rack. This scheme has been found a convenience for detecting missing stores.

A typical layout for instruments of the kind previously described is given in Fig. 27, in which is shown a steel rack with compartments for accommodating the various types of instruments. No attempt is made to vary the size of the compartments for the varying sizes of instruments, and a standard design of store rack is used. A number of modifications of this design are possible without detracting from its value, and that given in Fig. 27 is intended to represent only one type of storage rack which can be used.

Having dealt now with the more important instruments and accessories it remains to be said that the same principles should be followed when dealing with instruments other than those mentioned.

The instrument stores will also be found a convenient place to accommodate other small parts of aircraft, not themselves being instruments, such as bolts, nuts, pins and the like.

The instrument store, in common with the storage sheds for aircraft, should give accessibility to all the parts and be equipped with a system of fire extinguishers.

INSPECTIONS.

After aircraft or aircraft parts have been placed in store it is not sufficient that they be supported in the various ways described and then allowed to remain in these positions for a prolonged period. As has been stated, many of the materials of construction are liable, under varying atmospheric conditions, to deterioration, with the consequent loss of efficiency of the part in which these materials have been used. The corrosion of steel and the warping of timber are obvious examples of what will occur. During storage steps are taken to protect the parts as far as possible from these effects, both by excluding air from the material by the use of a grease film and by maintaining the atmospheric conditions within the storage sheds fairly constant, but even with these precautions there will always be a certain amount of unforeseen corrosion and deterioration, which if allowed to continue will eventually spread to such an extent as to render the material useless. To overcome these diffi-

culties, therefore, a system of inspections has to be formulated and its operation should detect the troubles in their early stages and give an opportunity for rectification. These inspections should take the form of ascertaining in detail the state of any stored part at periods of varying frequency depending upon the part concerned and the conditions under which it is stored. It is not intended that the inspections outlined should be rigidly adhered to, but their purpose is to show roughly the frequency and the detail of the inspections which are recommended. For consistency with previous descriptions, the inspections for complete aircraft will first be considered, to be followed up by those required on the various components.

Complete Aircraft.

The inspection of complete aircraft should be carried out once a month, the order for this work being as follows:—

The supports for the aircraft should be checked for being up to their work and any packing pieces which may have worked loose should be tightened up so that they carry their share of the load; in the case of wing supports when the wings are folded, these should be checked to prevent sagging of the wings. The complete aircraft should be wiped over for the removal of any dirt, and where old types of storage sheds are being used it should be ascertained whether water is leaking through the roof on to any part of the aircraft, and if so, a remedy applied. The covers should be removed from the engines and the engines turned through a few revolutions; if an engine is unduly sticky, thin oil should be injected before turning and any surplus oil run off from the sump. The undercarriage wheels should be clear of the ground and any settling down should be rectified by adding packing wedges under the undercarriage. A complete examination of the main plane fabric, struts, and bracing wires should be made, and if there are signs that the wing is suffering from internal defects, the fabric should be opened up round the doubtful part for inspection; it must afterwards be made good when the inspection is completed. In a similar way the structure of the fuselage should be examined, and in the types of aircraft where longerons of McGruer construction are used, these should be checked for faulty joints and to see that sagging is not occurring in any part of their length. The instruments such as are left in the aircraft during storage should be checked over, both for completeness and efficiency. Where the available space exists and an aircraft is stored with its main planes folded, the machine should be spread in order to check the alignment of the wing pins and locking bolts, after which it may be returned to its folded position. The coating of anti-rust preparation on metal parts should be cleaned off, the part rubbed down, and a fresh application of the composition made; this operation should extend to the metal struts of the undercarriage, the engines and all the external bracing wires. The tyres of the wheels should be examined for signs of perishing of the rubber, and it is an advantage to remove each wheel, clean the axle, re-coat it with anti-rust grease and replace the wheel.

In the case of seaplanes the same operations should be applied to the superstructure, but a special treatment is necessary for the floats or hulls, as outlined later. In inspecting these parts any opening of joints or other signs of the loss of watertightness should be detected. If hulls and floats have been coated with paint or other water-resisting material, this protecting surface should be intact, and if cracks have developed a fresh coating should be applied. Where arrangements have been made to maintain watertightness by placing water inside the hull, this water should at periods of inspections be removed to prevent stagnation and fresh water placed in the hull. During the summer months this operation will probably be required at every inspection, but during the winter it may be carried out at every second inspection. The internal metal fittings of the hull should be examined for signs of corrosion and the early stages of any corrosion removed and further developments checked by a fresh coating of anti-rust com-

position. For aluminium fittings a protective varnish consisting of one part of velure varnish and two parts turpentine may be applied.

In the foregoing manner the detail of the complete aircraft should be dealt with, and if these inspections be properly carried out there will be little opportunity for deterioration of the aircraft.

When complete aircraft have been in store for a considerable time, such as periods of one year or more, even though they are subjected to the monthly inspections as previously outlined, a further safeguard is recommended before any particular machine is taken into the air. This latter check on the safety of the aircraft is carried out by choosing a sample machine and subjecting it to strength tests, either up to the factor of safety of the design, or even to destruction. If the aircraft stands up satisfactorily to this test it may be reasonably assumed that the other aircraft are in a fit condition to be taken into the air.

Fuselages.

The inspection of fuselages should take place once every month and should be of such a character as will reveal any tendency to permanent deformation of the structure, either through inadequate supporting or variation in atmospheric conditions. The alignment of the structure should be checked over, which can usually be done by sighting along the longerons, and if any part is found to be sagging it should be further supported to reduce this tendency. In the case of wooden fuselages the longerons and struts should be examined for deterioration of the timber, and if any strut shows signs of weakness, steps should be taken to have a replacement fitted. The metal fittings and bracing wires should be gone over, and after being carefully cleaned down, should be re-coated with anti-rust composition. After this inspection the whole fuselage, when covered, should be cleaned down and any weak places in the fabric made good. Where the fuselages are stored complete with their fabric covers, the internal examination should be carried out by removing the fabric and if necessary cutting it away from the parts required to be inspected—it is easier to replace fabric on a fuselage than to rebuild the structure.

The above remarks are applicable to wooden fuselages, but those of metal construction should receive inspections with the same frequency, during which examination of the joints should be the central feature. If these joints are pinned and brazed there is a tendency for minute defects to develop during storage and these will show themselves as fine cracks in the brazing. For these reasons the examination will necessarily have to be intensive and need only be applied to sample fuselages. The protective composition which is cleaned off prior to examination will be substituted by a fresh coating when the examination has been completed.

Hulls.

The frequency of inspection for seaplane hulls should be of the same order as for fuselages, and for this inspection the chief point to consider is the watertight property of the structure. Resting as it does in a well fitting cradle and in view of the shape of the structure, it is unlikely that any distortion will occur. When the hull is stored with water inside, the tightness of the joints may be construed from an examination for traces of water either on the exterior of the hull or on the cradle; the water must then be emptied out before complete inspection of the hull. The inspection will then take the form of a detailed examination of the joints of the structure, both internally and externally and above and below the water line, after which the metal fittings may be examined and any corrosion removed—or if this be very serious the entire fitting removed—and a fresh application of protective composition made. If this inspection reveals a tendency for leakage, the hull structure may be coated with white lead paint,

which should be left untouched until it is quite dry. An external application only may be used first, and then if necessary on subsequent inspections, an internal application also made. If a renewal is required of the water in the interior of the hull, fresh water only should be used. The hull should be wiped over and fresh varnish applied where necessary. If water is not placed inside the hull the same object may be achieved by placing damp matting along the fins, this matting being damped occasionally to transmit the water to the joints of the hull structure. Under these conditions the matting will, of course, be removed for inspection and afterwards replaced in position. If the hull cradle does not allow a detailed inspection of the keel and bottom of the hull structure, the complete hull should be lifted from the cradle for this purpose, and either supported on temporary trestles while the cradle is removed, or suspended from an overhead gantry where such is available.

Main Planes.

The inspection of main planes should be carried out once every two months. Under conditions of rack storage a detailed examination of an individual plane is not possible with the plane in position in the rack. Each plane should therefore be removed in turn and placed where it can be inspected in detail. The whole plane, prior to inspection, should be cleaned, and in this way the defects of the fabric may be revealed. The metal fittings should have the treatment previously prescribed for such parts. Internal defects of the plane can best be located by feeling round the ribs outside the fabric, and if a particular place is thought to be weak, the fabric at that spot should be removed for detailed examination. In any case it is advisable to remove the fabric of one or two sample planes at the important points, such as the compression ribs, in order to enable a detailed examination of these parts of the structure; if the planes thus inspected are found to be satisfactory it will be a good guide as to the conditions of the other planes in the same store. When planes are stored on their leading edges and the conditions render it unavoidable that they must back on to a blank wall, there arises the possibility of damage owing to the attacks of vermin, so that when the planes are removed from racks of this nature their ends, which have been liable to this damage, should be inspected.

Inspections of metal planes need not be carried out with such frequency as those of the wooden variety, and once every three months should be sufficient for these types.

Control Surfaces.

A monthly inspection of these parts should be carried out, and in course of this examination the metal parts, being chiefly hinges and important fittings, require the most attention. Many of these components are of metal construction, fabric covered, so that apart from damage to the fabric there is little liability of depreciation of the structure. All these parts should, of course, be cleaned before inspection and afterwards have their exposed metal portions protected with grease.

Undercarriages and Chassis.

A monthly inspection of these parts should be sufficient to maintain their efficiency. With undercarriages stored in separate pieces, each part can receive separate inspection. In this category will be the undercarriage struts and axles with their fairings, and the inspection should determine that the fairings are properly attached to the struts and that the metal of the struts is receiving adequate protection. If the binding tape which is served round the fairing and the strut is weak, it will allow the fairing to twist round the strut, and in cases where this trouble has developed fresh binding tape should be used.

The wheels should be inspected for defects of the tyres. It is unlikely that the metal structure of the wheel will develop serious defects during storage, but where wheels are stored complete with tyres the possibility of the rim rusting where it is in contact with the tyre should not be forgotten, and a sample tyre here and there should be removed from the rim to investigate these conditions.

Shock absorber elastic calls for no special comment apart from the inspection of the state of the rubber, bearing in mind that this material perishes although not in use. Mechanical shock absorbers, such as are found on the Handley Page undercarriage and Oleo gear, should be dismantled for inspection, the parts cleaned, and if satisfactory the gear may be re-assembled with a fresh coating of grease.

The inspection of chassis for seaplanes is needed with about the same frequency as that of undercarriages, but in this case the possibilities of corrosion of the metal parts are increased by the effects of sea water. The examination should therefore be applied in detail to the struts and metal fittings and the same treatment accorded as for the protection of other metal parts of the aircraft. The serviceability of the floats should be checked with particular reference to their watertight properties and, if necessary, a fresh coat of water-resisting paint should be applied to the exterior after it has previously been cleaned. A few sample floats should be selected from the number in store and placed in water to see whether they leak. In this way the watertightness of the other floats may be estimated.

Wing Tip and Tail Floats.

A monthly inspection of these parts is recommended, and in course of this work the metal struts and other fittings should be treated and the watertight properties of the floats investigated. In cases of floats with fabric sides, the condition of this fabric should be examined with a view to renewal if any damage has occurred.

Bracing Wires and Cables.

With streamline bracing wires tied up in bundles, there is a tendency for certain protective compositions to flake off by contact of one wire with another, and further, if the wires have been bunched up before the composition is quite dry, one wire will stick to another, and in doing so, will leave a line of contact down each wire. When this has occurred and the wires are separated, it will be found that rusting has probably commenced where the wires have been in contact. For inspection of these parts, therefore, the wires must be separated from each other and all traces of such corrosion removed. They can then be re-stored as detailed previously.

Engines.

Complete engines or engine parts should be inspected every month. After having removed all the grease from the exterior parts, the engine should be turned through a few revolutions, and at the same time oil drained from the interior. A further supply of high-grade mineral oil, not castor oil, should be squirted into the cylinders and other working parts, such as gears and the like, and the turning continued to ensure that this fresh oil reaches all the interior parts of the engine. All traces of rust on the valve springs or other parts of the engine should carefully be removed before the fresh grease coating is applied. It is important when cleaning down the engine or removing corrosion, that all the ports or openings which admit to the interior of the engine should be kept covered to prevent the material removed from gaining access to the interior of the engine. After inspection, all the covers should be replaced.

Air screws.

The inspection of air screws should be carried out every two weeks, and should consist of an examination for lamination faults or warping of the blades. When air screws have been stored uncovered, either on pegs in the wall or on a rack, they may, if their location is inconvenient, be removed from their storage positions to obtain better access for a more detailed inspection. Prior to inspection the blades should be wiped over with a dry chamois leather to remove any moisture or dirt. Each joint between the laminations should be inspected throughout its length, and in cases where the blades are tipped with metal or

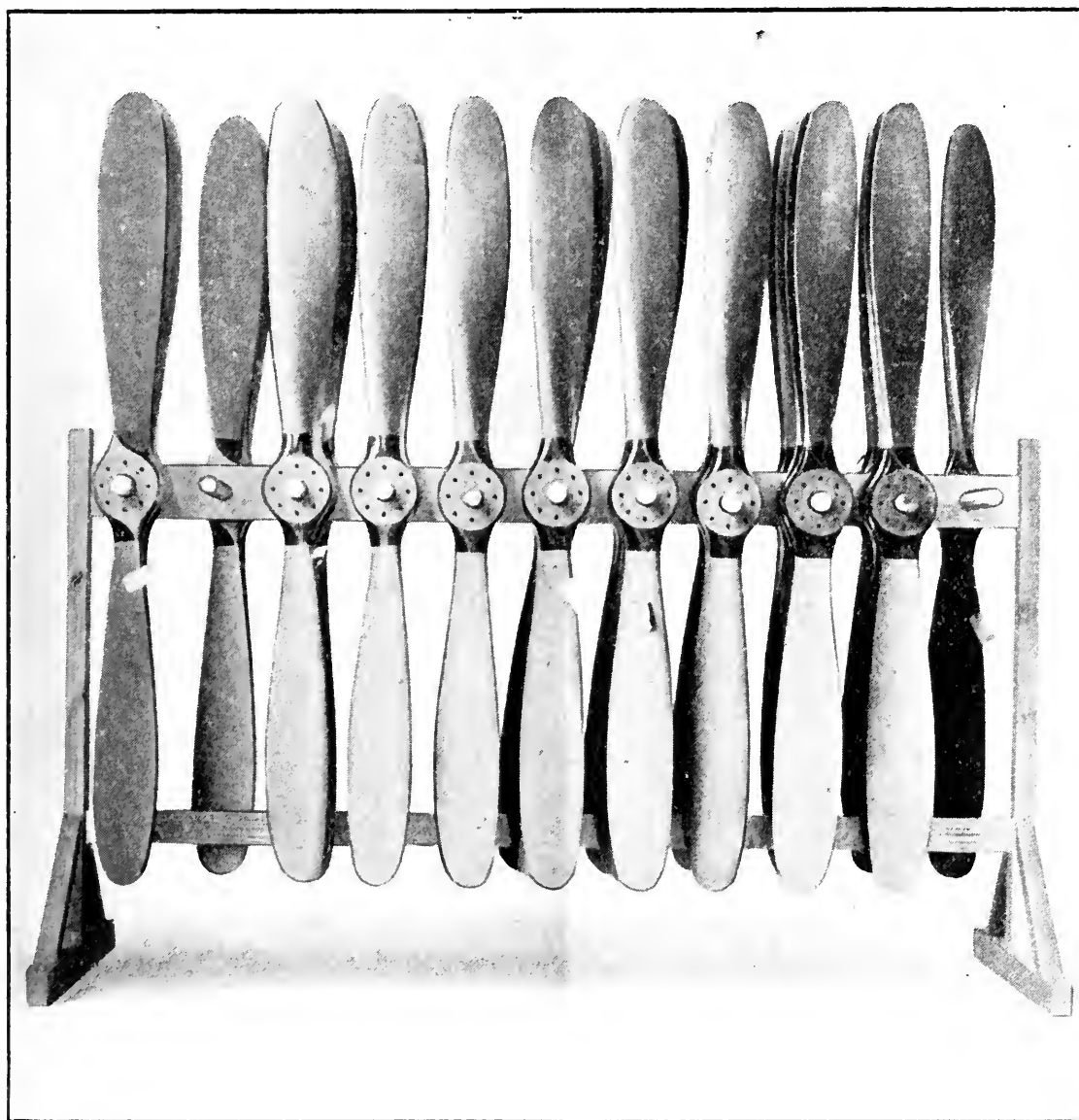


FIG. 26.—Air screws stored on Racks.

fabric, these local coverings should be secure. In a few instances such fabric covers may, either in the whole or part, be removed to expose that part of the blade for inspection; after this new covers should be secured in position. The varnished surface of the blades should be intact, and if there are signs of the surface disintegrating, the parts affected should be cleaned off and a fresh application of varnish made.

When air screws have been stored in their cases, they should, for purposes of inspection, be removed and afterwards replaced. In addition to these fortnightly inspections air screws should be turned once a week, four-bladed air-

screws being turned through 90 deg. each time, and two-bladed airscrews through 180 deg. It is of course obvious that no such similar operation can be carried out when the airscrews are stored in their packing cases.

Instruments and Accessories.

With the type of instruments in general use, inspections should be carried out about once every two months. During these inspections it is not possible to examine in detail the internal parts of each instrument, but external defects should be noted. As a guide to the condition of the instruments in store, one or two



FIG. 27.—*Instruments in Storage Bins.*

samples of each type should be selected, and these subjected to suitable tests. The behaviour of these samples under test will give an idea of the condition of the remaining instruments. These remarks also apply to engine parts, such as magnetos and all other accessories whose functions depend upon the action of mechanism.

Raw Materials.

Where raw materials are stored, frequent inspections are not so essential, but a periodical examination can be carried out on such materials as wood, fabric, rubber and the like, as these materials are more liable to deteriorate by ageing. The best method of determining the condition of these materials is to take samples and subject them to appropriate tests.

REVIEW.

The War in the Air (Official History of the Air). By Sir Walter Raleigh.
Oxford: Clarendon Press. 21s.

In reading a book published "by direction of the Historical Section of the Committee of Imperial Defence" one inevitably comes to consider the object of such official histories, what information they are intended to convey, and what class of reader they are designed to reach. In the case of the older services the answers would clearly appear to be that these publications are intended to provide documentary evidence of unimpeachable accuracy of the strategical and tactical dispositions of the rival forces at various periods, the reasons for those dispositions (where these are available or deducible) and their effects. The complete history then proceeds to draw lessons from this evidence; and the whole provides a valuable text book for the instruction of future generations who may have to apply the lessons, in the light of further experience and subject to such modifications as various changes may dictate. This book is to be judged from a different standpoint as an impartial account by a great literary stylist of the tribulations and achievements of some of those who had to wield a new weapon and fit it into the military machine. The decision to adopt this course may well have been correct in view of the difficulty of drawing any very definite instruction for the conduct of operations from the use of aircraft in the late war. Indeed, the tactics and strategy of the air, hardly even begun to be developed by November, 1918, are not much further to-day.

Sir Walter Raleigh, whose enthusiasm for his subject was no less notable than was his mastery of style, has provided the public with a most readable and in places enthralling narrative, often made to glow by descriptions from the mouths of the chief participants. This method, while indubitably infusing that life into the story which it was the author's desire to impart, has perhaps at times the defect of destroying the balance by giving undue prominence to certain incidents owing to the survival of the persons concerned. One regrets to say of a book produced under such auspices, that there appear to be inaccuracies here and there. It is, for example, somewhat surprising to be told that the Dunne aeroplane of pre-war days "took hints from the zannonia (*sic*) leaf," when in his paper before this Society, on January 29th, 1913, Mr. J. W. Dunne himself said,* "Violently opposed to the zannonia leaf type in most characteristics are the wing forms in . . . the division to which I have given my attention since 1904."

Or, again, in recording the early experiments with balloons in 1783 the Christian names of the two Montgolfier brothers are given as Joseph and Jacques, whereas the latter is referred to in all contemporary accounts as Etienne.

The lack of an index, which is presumably being reserved for a later volume, makes it difficult to be certain of omissions. There appears to be, however, no mention of the "Morning Post" Lebaudy or the Clément-Bayard airships, or of the patrol of Parseval No. 4 airship over the approaches to the Thames on the night of August 5-6, 1914, which antedated the first operations of the R.N.A.S. (August 8) and R.F.C. (August 19) recorded. Without the aid of an index it is difficult to be absolutely certain on these points, but a careful reading of the book has failed to reveal them. Altogether one is inclined to think that less informa-

* Aeronautical Journal, Vol. XVII., p. 86.

tion must have become available as to the early work of the R.N.A.S. than of the R.F.C., though the notes on the organisation of the latter in the chapter on "The Expansion of the Air Force" are surely open to criticism.

Reference has already been made to the literary character of the writing which of itself makes this book acceptable. No one else could have depicted half so well the romance of the eighteenth century balloonists or the early struggles of the aviation pioneers of a hundred years later, and when the author comes to deal with the first participations of the new arm in the war he pays a worthy and touching tribute to the matchless courage and devotion of the men who were called upon to found the traditions of the flying services. Sir Walter Raleigh's death when only at the outset of his task is a loss which will be for ever deplored and must inevitably change the character of the account in future volumes, since it will be hard for whoever succeeds him to breathe quite the same spirit of romance into the narrative.



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AUGUST, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Silver Medal.

At a Council Meeting held on July 18th it was decided to award the Society's Silver Medal for 1921 to Mr. H. Ricardo for his paper entitled "Some Possible Lines of Development in Aircraft Engines." The Silver Medal will in future be awarded annually to the author of the paper which is, in the opinion of the Council, the best of those published in the AERONAUTICAL JOURNAL each year.

Finance.

A statement of accounts for the six months ending June 30th, 1922, has been prepared in the office and presented to the Council. It is regretted that this discloses an excess of expenditure over income of £75 19s. 4d. It is hoped, however, that the remainder of the year will produce a sufficiently satisfactory result to leave only a small deficit on the whole year's working.

Journal.

It is gratifying to find that the number of subscriptions to the JOURNAL from persons outside the membership of the Society has recently been increasing considerably. Technical members of the Society can materially assist in this direction by forwarding contributions embodying the results of their work to the Editor.

Usborne Memorial Fund.

It is regretted that the subscription of 25 guineas towards this Fund from Sir Trevor Dawson was inadvertently credited to the Pilcher Memorial Prize for Students. This increases the total of the Usborne Fund to £99 14s. 0d., and involves a corresponding decrease in the Pilcher Prize to a total of £111 0s. 0d.

Examination.

The first Associate Fellowship examination, in accordance with the new regulations, will be held on Monday, September 25th (Part I.), and Tuesday,

September 26th (Part II.), in the Library at 7, Albemarle Street, London, W.1. Entries, accompanied by the prescribed examination fee, should reach the Secretary not later than Monday, August 28th.

Office Closing.

Members are reminded that the Offices and Library will be closed for annual cleaning until August 15th.

W. LOCKWOOD MARSH, *Secretary.*



PROCEEDINGS.

TWELFTH MEETING, 57th SESSION.

A meeting of the Society was held in the rooms of the Royal Society of Arts, Adelphi, London, on Thursday, April 6th, 1922, the Chairman (Lieut.-Colonel M. O'Gorman) in the chair.

The CHAIRMAN said that the members were to hear M. Louis Breguet, whose name they were too well acquainted with to need any introduction from him. The members ought to know, however, that M. Breguet had been decorated in 1911 and subsequently promoted to the rank of officer of the Legion of Honour, in France, for the services he had rendered during the war, and moreover, that he was the President of what corresponded, in France, to the Society of British Aircraft Constructors, namely, the *Chambre Syndicale des Industries Aéronautiques*. (Applause.)

The CHAIRMAN then called upon M. Breguet to read his paper on "Aerodynamical Efficiency and the Reduction of Air Transport Costs."

AERODYNAMICAL EFFICIENCY AND THE REDUCTION OF AIR TRANSPORT COSTS.

The possibility for aeroplanes used in air transport services to be made to pay has, so far, been very often questioned, considering the present cost price per ton-mile flown.

I intend to demonstrate that one can, from now, predict an important reduction in air freight rates, not only through greater safety of flight mainly resulting from a longer life of aeroplanes and engines, but also through the betterment of several coefficients which characterise the aerodynamical qualities of aeroplanes.

The study of these coefficients can be made either by laboratory tests on models or by full-scale tests in flight which, if judiciously interpreted, should yield information sufficiently accurate for practical purposes.

May I remind you that the principles of aerodynamics lie in the following formulæ:—

$$R_x = (K_x + \sigma/S) S V^2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

wherein:—

R_x is the total drag of the whole aeroplane along the direction of motion.
 K_x is a coefficient relating to R_x and dependent upon the value of the angle of incidence in flight.

σ is the projected area, normally to the direction of motion, representing the passive resistances of the aeroplane.

S is the projected area of the wings on a plane parallel to the direction of motion.

V is the speed of the aeroplane along the trajectory.

$$R_y = K_y S V^2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

wherein:—

R_y is the lift of the aeroplane, normal to the direction of motion.

K_y is a coefficient relating to R_y and dependent upon the value of the angle of incidence in flight.

Dividing equation No. (1) by equation No. (2), which gives the ratio of drag to lift, we have:—

$$R_x/R_y = (K_x + \sigma/S)/K_y = \tan \phi \quad . \quad . \quad . \quad (3)$$

That expression $\tan \phi$ is usually called the “fineness” of the aeroplane, and every aeroplane is characterised by a certain minimum value of $\tan \phi$ which can be represented by $\tan \phi_m$. The smaller $\tan \phi_m$ is the better will be the aerodynamical qualities of the aeroplane.

That fineness is used when calculating the longest distance which a given aeroplane can fly in a “no wind” atmosphere.

$$L = (622 \rho/m \tan \phi_m) \log P/(P - p) \quad . \quad . \quad . \quad (4)$$

wherein:—

L is the said longest distance in kilometres.

ρ is the efficiency of the propeller.

m is the “fuel and oil” consumption of the engine per horse-power and per hour in kilogs.

P is the total weight in kilogs. of the aeroplane and cargoes at the start.

p is the weight in kilogs. of the “fuel and oil” consumed by the engine during the flight and which was included in P .

One at once realises the very great importance of the fineness $\tan \phi_m$ which in that formula is the only term depending upon the aerodynamical qualities of the aeroplane.

For certain given values of L , ρ , m and P , a reduction of $\tan \phi_m$ causes a reduction in the “fuel and oil” consumption, and consequently increases the weight of paying freight which could be carried.

The conclusion is that one must bring to the minimum the value of $\tan \phi_m$. It can be obtained by choosing the best possible profile for the wings, the best designs for the body, empennage, etc. Moreover, the undercarriage should be made to disappear inside the body or the wings when the aeroplane is in flight, etc.

Another interesting coefficient appears when one calculates the power spent in horizontal flight is given by the formula:—

$$W = R_x V = (K_x + \sigma/S) S V^3 \quad . \quad . \quad . \quad (5)$$

where

W is the power in kilogrammetres.

R_x is the drag in kilogs. as calculated by formula (1).

S is the wing area in square metres.

V is the speed in metres per second.

On another side, the value of the lift, as given by formula (2), is equal to the total weight P of the aeroplane in horizontal flight. We thus have:—

$$P = R_y = K_y S V^2 \quad . \quad . \quad . \quad (6)$$

Eliminating the speed V between the two equations (5) and (6) we come to another formula giving the power W :—

$$W = P \sqrt{(P/S) (K_x + \sigma/S)/(K_y)^{3/2}} \quad . \quad . \quad . \quad (7)$$

We thus see that the necessary power is in direct proportion to the value of the term

$$(K_x + \sigma/S)/(K_y)^{3/2}$$

I have represented the term by the Greek letter ζ and call it the *coefficient of power*.

For a given aeroplane, the value of ζ will reach a minimum for a certain angle of incidence in flight, and to that particular value of ζ will correspond the minimum of power required, and that is why I propose to call that special value ζ_m the *coefficient of minimum power*.

That coefficient of minimum power is used to calculate the minimum power necessary to maintain in horizontal flight a given aeroplane, and the height of ceiling chosen will fix the nominal power to be provided for the engine. One can therefore see that, should it be possible to reduce in the proportion of two to one, for instance, the value of ζ_m , then an engine of half the nominal power would be sufficient to reach the same ceiling.

Since I have now clearly shown the way these several coefficients affect the aerodynamical qualities of aeroplanes, I can explain to you how one can design in the future, starting from existing aeroplanes, new ones which should reduce by more than one half the present rates of aerial freight, and how also, when bringing other improvements which I will specify later on, one can expect to bring down the rates of aerial freight to the value of those now charged in France for first class railway passengers.

An aeroplane of high standard quality now has:—

A fineness equal to	...	...	...	...	...	0.12
Its coefficient of minimum power is equal to	...	...	...	...	...	0.55
Its propeller efficiency is	...	...	...	...	...	0.73
Fuel and oil consumption of its engine at an altitude of 2,000 metres is 290 grammes per horse-power and per hour.						

We will, moreover, admit the total weight of that aeroplane to be such as to allow it to climb to 4,500 metres within one and a half hours if the engines are run at full power,* and we will consider an aerial line of 800 kilometres non-stop flights.

If such an aeroplane has a wing surface of 100 square metres, for instance, and a power plant of 600 horse-power, its dead weight will be equal to 2,200 kilogs., and it will be able to carry a total load of 2,100 kilogs. Its total weight will thus be equal to 4,300 kilogs.

Its flying speed at full power at an altitude of 2,000 metres will reach 175 kilometres an hour, and its commercial speed at the same altitude can be reckoned as to be equal to 150 or 155 kilometres an hour.

The weight of fuel and oil necessary in a still atmosphere for a given flight is deduced from the formula (4), which, in the present case, gives the weight as being 568 kilogs.

But practical flying has proved that one must expect to have to fly against a fifty kilometres an hour wind, and therefore it is necessary to have at least a fifty per cent. safety margin in fuel and oil. In other words, we shall have to carry in the case under consideration a total weight of fuel and oil equal to $568 \times 1.5 = 850$ kilogs., whilst the average consumption will only be of about 1.1 times the calculated quantity of 568 kilogs., that is to say, 625 kilogs.†

The crew (pilot and second pilot-mechanic) together represent a weight of about 180 kilogs., and another 70 kilogs. are necessary for various instruments and T.S.F. apparatus.

The total weight of fuel and oil, crew and instruments thus reaches eleven hundred kilogs., leaving a clear margin of one thousand kilogs. for passengers and paying cargo.

* It means that the nominal power of the engines, multiplied by the propeller efficiency, must be equal to about two to three times the minimum power necessary for horizontal flying at sea level.

† The coefficient 1.1 is the average of data registered on several hundred flights.

The present running costs of an aerial line of 800 kilometres long, with the above aeroplanes, are as follows:—

	Francs.
Petrol (820 litres at francs 1.82 for 800 kilom. flown) per kilom.	1.87
Oil (50 litres at francs 3 for 800 kilom. flown)	0.19
Crew (pilot at francs 0.20 per kilom., second pilot-mechanic at francs 0.15)*	0.35
Sinking fund for aeroplane and engine	6.50
Upkeep of aeroplane and engine and aeroport expenses, etc. ...	4.50
General expenses of the company	4.00
	<hr/>
	Francs 17.41

Should an aeroplane always fly with full cargo load and without incident or interruption, the cost price per ton and per kilometre would thus be about 17.40 francs. But one has to reckon with trips made with smaller paying loads, or incidentally interrupted, and therefore it is wise to calculate the cost price per ton on flights with half cargo loads as an average, which brings the present cost price per ton and per kilometre to 35 francs. That is about the price at which are now working the best aerial lines. A few companies work on still higher prices, either because the average cargo load is less than one half the maximum, or because they fly over particularly awkward grounds. They then reach such prices as 50 francs or £1 12s. od. per ton-mile.

Should such prices be considered as irreducible they would be practically prohibitive and little chance would be left to commercial aviation, since one would have to charge from eleven to twelve hundred francs per passenger from Paris to London or vice versa, without any profit to the company.

How can these figures be reduced in the near future? We will consider:—

- 1.—Advantages to be drawn solely from the betterment of aerodynamical qualities of the aeroplanes and of the thermal efficiency of engines.
- 2.—Advantages resulting from such improvements in the engines and in mechanical parts of aeroplanes as would bring reductions in the provision for sinking funds, upkeep of machines and general expenses.

1.—Advantages to be drawn solely from the betterment of aerodynamical qualities of the aeroplanes and of the thermal efficiency of engines.

Taking, for the sake of demonstration, the same size of aeroplane as already considered, that is to say:—

Wing area: 100 square metres.

Total weight: 4,300 kilogs. at the start.

Ceiling: 4,500 metres.

And if we suppose that we can bring down:—

Its fineness to	0.065	instead of	0.12
Its coefficient of minimum power to	0.28	„	0.55
Its propeller efficiency to	0.775	„	0.73
The fuel and oil consumption of its engines per horse-power and per hour to	215	„	290 grams

* Several companies now have to spend an average of 0.50 francs per kilometre for the crew, but that is because their lines are rather short ones (say, 375 kilometres on Paris-London), and also that the crew only flies one single trip a day, and not every day. With the present minimum of salary one has to guarantee them, as also with the number of pilots one has to keep according to subsidies-regulations, these pilots are far from rendering efficient work (from "distances flown" point of view). The figures I have taken of 0.35 francs apply to lines of some 800 kilometres, a few of which are now in contemplation.

then such an aeroplane will not require more than 288 horse-power to reach the same ceiling of 4,500 metres instead of 600 h.p.

It is evident that the reduction in power is only due to the betterment of the coefficient of minimum power and of the efficiency of the propeller.

One can thus spare 312 horse-power, which means a saving of 468 kilogs. of dead weight (at the rate of one and a half kilogs. per horse-power for the engine and its appliances).

The quantity of fuel and oil to be carried can be deduced from the formula (4), as has already been done for the first type of aeroplane considered. This gives

$$p = 230 \text{ kilogs.}$$

The weight it is wise to carry up will be taken equal to

$$230 \times 1.5 = 345 \text{ kilogs.}$$

and the average actual consumption will be about

$$230 \times 1.1 = 255 \text{ kilogs.}$$

The weight saved on fuel and oil with the second type of aeroplane will thus be practically

$$850 - 345 = 505 \text{ kilogs.}$$

and the excess of useful load is thus increased to a total of

$$468 + 505 = 973 \text{ kilogs.}$$

The commercial efficiency of that type of aeroplane will thus be practically double that of the first type, since it will be able to carry 1,973 kilogs. of passengers or paying freight, instead of 1,000 kilogs.†

At the same time that aeroplane will cost about 25 per cent. less than the first, since its nominal power plant will only be half the size of the first, and the value of the nominal power plant now represents about half the price of an aeroplane.

The running cost of the new type of machine will then be as follows:—

	Francs.
Petrol (335 litres at francs 1.82 for 800 kilometres) per kilom.	0.765
Oil (20 litres at francs 3 for 800 kilometres)	0.075
Crew	0.35
Sinking fund (75 per cent. of francs 6.50, since the cost price of the aeroplane has been found reduced in that proportion)	4.90
Upkeep of aeroplane and engine and aeroport expenses ...	4.50
General expenses of the company	4.00
	<hr/>
	Francs 14.59

As the paying load has been raised to 1,973 kilogs., the cost price per ton and per kilometre becomes equal to 7.40 francs, or—if calculated on a half cargo load basis—14.80 francs instead of the present cost price of 35 francs. London to Paris passenger fares can then be brought down to some 450 or 500 francs without profit for the company. Although very high, these last figures are more encouraging and nearly workable.

† As a matter of fact, one should deduce from that weight some 180 to 200 kilogrammes for the accommodation of the surplus of passengers and freight. But on another side one can reasonably expect that the daily progress made in the manufacture of aeroplanes and the use of stronger material will allow saving on dead weight of practically the same amount.

2.—Advantages resulting from such improvements in the engines and in mechanical parts of aeroplanes as could bring reduction in the provisions for sinking funds, upkeep and general expenses.

When one can rely on an average life of one thousand hours for aeroplanes and engines instead of the present 200 or 250, much better prices will be obtained. Supposing that such an aeroplane be bought for the same price as the last one mentioned, but calculating on 1,000 hours life, the sinking fund only calls for 1.10 francs, whilst the upkeep can be reasonably considered as half as expensive since the aeroplanes and engines will be of much better quality and strength. General expenses will also be considerably reduced through the much larger turnover that the companies will then be able to secure.

In such conditions the running costs would be as follows:—

Petrol	per kilometre, francs	0.765
Oil		0.075
Crew		0.35
Sinking fund		1.10
Upkeep		2.25
General expenses (estimated)		1.00

Francs 5.54

That is to say, 5.55 francs for 1,973 kilogs. carried, or 2.82 francs per ton and per kilometre, or 5.65 francs if calculated on the usual half cargo load basis. Then the Paris to London fare will become about 190 francs, or say £4, the present price of the third class railway fare.

When that time comes then the aerial transport companies will be flourishing paying concerns, and no more subsidies will be required from the State, because the time saved in travelling by air from Paris to London, for instance, will certainly be worth a fare of say £6, showing £2 profit on each passenger.

It is worth noting in the last cost price we have given that fuel and oil, although intrinsically very expensive, amount to only fifteen per cent. of the total cost price, whilst the crew draws 6.4 per cent.

On the other side, sinking fund, upkeep and general expenses, which, on the present cost of 35 francs, represent 86 per cent. of the total cost price, have grown to 92 per cent. with the second example and come down to 78 per cent. in the last considered circumstances.

May I therefore state—in opposition to the sayings and writings of certain experts who do not know much about aerial transports—that it is not the cost of fuel or crew which makes aeroplanes expensive machines, but only their present short life, with resulting consequences. But we must expect and hope to see large and strong aeroplanes of the future become as safe as motor cars, steamships and railways, and when that time comes, then we will be able to apply to sinking funds the same coefficient as is now used for steamships, that is to say, about an average life of twenty-five years!

From the example I have taken for the purpose of demonstration of an aeroplane of one hundred square metres wing area and 4,300 kilogs. total weight, you must not infer that I expect the improvements of aerodynamical qualities (with the consequences I drew from it) to be realised by such small machines. I believe one can build very good aeroplanes of four to five tons total weight; but I think it would be much nearer to reality to talk of 500 square metres wing surface, twenty to forty tons total weight and fifteen hundred to four thousand horse-power. Such large machines* will most probably have very thick wings.

* Which being probably much more heavily loaded per square metre will be able to reach speeds of about 150 m.p.h.

By thick, I mean about six feet, and within these wings will be provided cabins, saloons and every comfort for passengers. It is worth noting that if a large increase of the size of an aeroplane does not improve materially its commercial efficiency, it has nevertheless the great advantage of allowing much more room for passengers and freight, and that can be easily understood when one remembers that whilst the weight, the power, the capacity in cargo and the cost price of an aeroplane vary as the square of its lineal dimensions, the volume to be reserved for passengers will vary as the cube of the same dimensions. In other words, if the weight, surface and power have been increased one hundred times, then the cubic capacity will be one thousand times larger.* Passengers, for instance, will proportionately dispose of ten cubic metres each instead of one cubic metre in the first case, and that shows one of the most important advantages to be drawn from the manufacture of very large machines.

It is not exaggeration to talk of the days when the price of aerial transport will come down to two francs per ton and per kilometre, since an average life of two or three years—or say two thousand hours of flight—for aeroplanes and engines would suffice to bring that result, even with petrol and oil at their present very high prices. It is practically certain that aeroplanes of the future will not burn petrol but rather heavy oils or other cheap fuels, the cost price of which should be about one-fifth that of petrol.

Now first class passenger fares in France are calculated on the basis of 21.15 francs per one hundred kilometres. Supposing that a passenger with his hand luggage weighs an average of ninety kilogs., we find that the ton-kilometre (passenger) runs to 2.35 francs. That shows that the future prices of aerial transports will be of the same order as the present first class passenger fares in France.

More striking still is the comparison with the fares on steamship lines, since a first class passenger nowadays pays about six francs per ton-kilometre, whilst state cabins are charged at the rate of ten francs.

In conclusion, aerial transports are very expensive for the present because they are not yet out of the experimental stage and that the sinking funds, the upkeep and general expenses are very heavy; but one can reasonably say that within ten years these costs should be reduced in the proportion of seven to one, and within twenty years roughly in the proportion of fifteen to one.

Moreover, one must not forget that "time is money," and therefore a saving of four or five days on London to Cairo, for instance, will be of tremendous value to business men. The fares charged will then be of comparatively small importance to them as long as safety and speed are secured, and as aeroplanes will be unbeatable as regards speed, aerial transports are bound to wipe out all other systems of international communications.

We must therefore work hard and steadily, with full confidence in the future of aviation.

DISCUSSION.

The CHAIRMAN said they had listened with interest to M. Breguet's display of an optimism which was well worthy of their respect. He had indicated the steps by which they might compete on equal terms with railways for certain classes of traffic, and if they did not arrive at the whole result they might look step by step at the various factors and see which of them they had failed to bring up to the high level which had been foreseen. He had suggested that the fineness of aircraft could be improved by 50 per cent. He had shown the hope that fuel consumption might be reduced, and had discussed similar factors, showing that

* If the aeroplanes have been built from the same drawings read on a larger scale.

even if these factors of improvement could not all be obtained *in toto*, he had shown that the sum of the advances obtainable make a fundamental and logical improvement in the whole aeronautical situation. M. Breguet's optimism was legitimate if the moneys spent on research were not reduced. Each specialist could then tackle, in his own sphere, some one of the problems that M. Breguet had exposed, and in such measure as they secured improvement, these would become operative together, and we should approach the competition, on an equal basis of charge, of first class railway fare and travel by aeroplane, with the enormous advantage to the aeroplane traveller that he had saved so much in time. With regard to the author's prophecy of the 40-ton monoplane, he did not suppose that an engineer of the author's distinction would have put that forward entirely at random without having thought it out as a thing thoroughly worth considering as a commercial possibility. The author had shown that the real incoming of aerial transport was not going to be achieved by prophetic letters to the Press nor yet by meetings of the Civil Aviation Advisory Board at the Air Ministry, unless the latter proved themselves competent to understand the technical nature of the problem and secured a sufficient addition of funds for the specialised research which civil transport needed. He agreed that civil transport was the basis for full factories and full factories the basis of military aeronautical operations. Nothing else but the scientific work of men of intelligence and intellect in the laboratory and in the air would solve the technical problems; and nothing but a solution of the scientific problems could make air transport self-supporting. Everyone would agree that that was the solution to be obtained. It was deplorable to realise that the authorities seemed so little capable of realising this, that they allowed the technical and research expenditure to be cut down with a view to national economy; he felt very strongly that this was simply national extravagance. It was killing that which alone could economically keep the aircraft factories in being in the state necessary to provide the fighting machines for aerial defence—Britain's, and indeed any country's, first line of defence.

Mr. F. HANDLEY PAGE said it was very interesting to have M. Breguet to address a meeting of the Royal Aeronautical Society. He had been one of the great pioneers of aviation, and one who had devoted himself not merely to the type of aircraft that they saw flying to-day, but he believed some of his earliest efforts were in the direction of the helicopter, which, if it had not produced practical results, had at least produced a very lengthy correspondence from the inventors. In having M. Breguet at the meeting the Society was greatly honoured. He (the speaker) was an optimist; his optimism was not based merely on the feeling that the success of air transport depended solely on the research laboratory, which the President had emphasised. It had been very much borne in upon him during the last few days that even with the latest and best of up-to-date machines they did not necessarily achieve an air service. An air service was dependent, quite apart from equipment, on the ground organisation that dealt with it. If we were able to make machines that we could run at one-third, or one-fifth, or even one-fifteenth of the present-day cost, that would not make possible a flight to Paris in thick fog and low clouds, and it would not enable the pilot to know whether he could start now or in an hour's time unless the meteorological service was very good. It was the improvement of the adjuncts to an air service, quite apart from the machine itself, or the skill of the mechanics who looked after it, or the pilots who flew it, that would make development possible. If it were possible to fly present-day machines in all weathers strictly to scheduled time, and for them to return strictly to scheduled time, no matter what the weather was, costs would be very considerably reduced as well as charges to the public. He had looked with great interest at the formulæ in the paper and he did not know whether there was a solution to any of those equations that gave one the value of profits. It seemed to him that if they could determine that accurately by means of an equation it would be an excellent thing for mathematical treatment. As a distinguished mathematician had said, "What comes out of the mathematical

mill depends on what you put into it," but there were so many variables in arriving at a result by mathematical methods that it was necessary to study the component factors entering into it before they could arrive at a figure for the profits they were likely to get. He laid stress on the particular item of the ground organisation. He was very much interested to see, in the latter part of the paper, M. Breguet's visualisation of the very large aeroplane. The difficulty of structure weight had always seemed to him to be rather insuperable if they went beyond a certain size. In the four-engined machine made by his firm, which weighed 30,000lbs., it seemed that they were gradually approaching the point where materials had been used to the best possible advantage, and there seemed little possibility of improving the use of those materials and getting over the theoretical disadvantage that was attendant upon increased span. He did not know whether M. Breguet, with his great engineering skill, had thought of any method by which that disability might be overcome. Without a doubt, were it possible to obtain a scale effect with larger sized machines, by which they could fly with greater loadings per square foot and thus decrease the span, such an improvement might be possible. In that direction it was rather interesting to know that in nature some of the bigger birds which, he was assured by Dr. Hankin, flew at the same speed, carried a greater load per square foot, although their landing speed was the same. It would appear that nature had got over structural difficulties by introducing a scale effect. Whether it was possible to utilise that in a very much bigger way in the construction of large machines he did not know. Perhaps M. Breguet could say something about it. He again thanked M. Breguet for his interesting paper, and congratulated him on having read it in English.

Captain GOODMAN CROUCH congratulated M. Breguet on his very interesting and rather optimistic paper, and the Society on having the opportunity of listening to one of the earliest pioneer aviators of France, who was also one of her greatest engineers.

He recalled that he had had the honour of being associated with M. Breguet in aviation some 10 years ago, when he (M. Breguet) put into the air a type of aeroplane which was called a double monoplane, since it was so unlike the usual box kite form of biplane then known. People looked at this curious beast and asked what it was, since with biplane wings it had a fuselage and was almost entirely of metal construction. One had only to consider the machines of a few years later to realise that M. Breguet was a true prophet, for it would be remembered that he alone at that time was the designer working on those lines.

With regard to the air transport costs quoted by M. Breguet, the list of prices shown for running costs of an aerial line of 800 km. length included an item of Frs.6.50 for sinking fund out of a total of Frs.17.41. This, in his opinion, was a remarkably high percentage. It indicated that in the hypothetical case M. Breguet had taken he had chosen a machine presumably with a far shorter life than that of present-day aircraft, and he believed this item could be considerably reduced. This appeared to be borne out by the length of life assumed by M. Breguet when considering the advantages resulting from such improvements in engines and in mechanical parts, as could bring reduction in sinking fund and upkeep charges. Under this head M. Breguet had assumed the life of present-day machines to be 200 or 250 hours, and predicted the possibility of improving this to 1,000 hours.

Captain Crouch ventured to suggest that even during the war the life of 250 flying hours had been reached, and even surpassed by some of the heavy bombers, and the figure of a 1,000 hours was hardly a prophecy since a total of approximately 800 hours had already been reached by a machine on the London-Paris Service.

With regard to the advantages hoped for from the betterment of aerodynamic

qualities, M. Breguet's fineness coefficient indicated a figure for L/D of approximately $18\frac{1}{2}$. This appeared to be optimistic, but he dare not say much in criticism of the point, since M. Breguet had already shown himself to be a true prophet. Recent aerodynamic tests on a model of a Woyevodski type had given a maximum L/D of about 12, and that, as far as he knew, was the highest figure yet reached for a complete model.

M. Breguet's remarks concerning future large machines were teeming with interest, but he felt that M. Breguet was extraordinarily optimistic in assuming that the increase in volume available for passengers would be so much greater than the increase in weight, power and cost.

Finally, he again thanked M. Breguet for the lecture, which from a technical point of view gave so much food for thought.

Mr. W. O. MANNING said he was sure everybody appreciated the honour M. Breguet had conferred upon them by reading his exceedingly interesting paper. Those who had followed aviation from the early days would remember the large series of aeroplanes known as the Breguet type, and the brilliant engineering design that invariably characterised them. He endorsed what Captain Goodman Crouch had said to the extent that, although he was not connected with commercial aviation, he certainly expected that the life of aeroplanes and engines to-day in commercial work was considerably longer than 250 hours. He was not an engine builder and could, perhaps, speak with less bias on that particular point, but he knew he could introduce M. Breguet to one or two English engine builders who could beat that performance. It would give them a great deal of pleasure when they remembered that in the early days of aviation practically the whole of English aviation was dependent upon French engines if they were able now to return the compliment. M. Breguet had done a very great service to aviation by pointing out the enormous importance of improvement in aerodynamical efficiency. One tried to improve the efficiency of the machines, but one did not appreciate, until it had been pointed out so clearly, what a very important matter aerodynamical efficiency was, not only in the saving of engine power, but in increasing the useful load and in cheapening the cost of the machine. With regard to M. Breguet's large machine, he was, of course, up against the dimensional law that the weight went up considerably faster than the area and that there is a definite limit of size for machines of present-day construction and design. But it by no means followed that the limit was the same for other types. It was possible that a very large monoplane, such as that referred to by the Lecturer, presumably with high-lift wings, and with the passengers, fuel, engines, etc., distributed along the wings, might be capable of being constructed for a reasonable weight. He again thanked M. Breguet for his interesting paper.

Colonel W. D. BEATTY joined with previous speakers in congratulating M. Breguet upon having read his paper in English. There was one point which had struck him, and that was in regard to the symbols used. The efficiency factor he had assumed corresponded to our English L/D . Although there were exceptional cases where the technical experts in the two countries did speak each other's languages, the majority did not, but it was obviously desirable that they should all think in the same mathematical language. With regard to that he was glad to say that preliminary steps had already been taken, in conjunction with the French Air Ministry, in order to get down to the same basis in England and France. While he did not wish to plunge into the argument as to the possibility or otherwise of the very large machine, he felt rather glad that there seemed to be such hope for the future. We still had a lot to do in the way of building up the traffic necessary to make it commercially practicable.

Mr. O. T. GNOSPILIUS, after expressing his interest in the Paper, congratulated M. Breguet upon his courage in assuming that what we called L/D , or efficiency of the machine, could be improved, because he was quite sure, by his own

experiments, that it could be done. They knew that certain experiments had been done at the N.P.L. and other places, and they got certain results, but if one made experiments one's self one got quite a different outlook. He was sure M. Breguet was quite right in saying he could get something like 15 to 1 L/D , because he himself had made pieces of wood in the shape of bodies, wings and tails which gave that effect, so that he did not see why the complete machine should not do the same. The trouble was that we did not know much about aerodynamics, and did not know the proper shape to make. It seemed to him that work on that line was very essential, because 15lbs. per h.p. was not practicable; we wanted to turn it into 30. In present machines the figure was more or less 15lbs., and he was very glad that M. Breguet had brought forward this sort of figure for efficiency.

Mr. A. P. THURSTON said that the lecture impressed one very much indeed, that famous men, like science, were international. We (in England) more or less regarded M. Breguet as one of ourselves, and felt it a very great honour to receive a lecture from him. He was a pioneer of many things, but it was not realised that over 1,000 of M. Breguet's all-metal machines were actually used in the fighting line during the war. That was a very considerable achievement.

M. Breguet had brought out very clearly that to increase the efficiency of a machine it was necessary to reduce the "useless surface" (surface invisible) to the minimum amount, and the ingenuity of our designers must be utilised in taking off all extraneous corners and everything which caused waste by increasing that surface. But there was a point which was not, perhaps, brought out quite so clearly, and that was that the efficiency in carrying weight per distance could be increased by actually increasing the speed of the machine and decreasing the lifting area. The great difficulty in this connection was that of landing speed. But there were ways of doing it which would enable them to get a higher speed still in the air with smaller surface, and yet maintain slow landing speeds. In other words, it was possible, as suggested by Mr. Handley Page, to get something of a scale effect by taking advantage—he was not at liberty to say how—of certain properties of the air. He did think that it would be possible to increase the present efficiency of our machines in order to get a greater weight mileage for a certain expenditure either of money or of fuel, and in that way increase the possibilities of commercial aviation. He had once taken the trouble to go through the figures, taking a line to India. Assuming there were a large number of machines, taking the cost of maintenance of grounds, and petrol at 2s. per gallon, assuming the organisation was so perfect that each machine could be flown for 10 hours a day, and each machine would last on an average two years, on that basis he had made out that it was quite possible to maintain a good dividend and charge passengers at the rate of 3d. per mile.

With regard to M. Breguet's remarks about engines, he would like to endorse what was said by Mr. Manning. It was only a few days ago, at Croydon, that a Napier Lion was pointed out which had been running continuously for 450 hours without being taken down. It was possible for British engines to do better still, and attain running efficiencies which would be considerably better than the 220 hours of the French engines.

He also endorsed M. Breguet's remarks as to aviation being the greatest future means of international communication, and in conclusion took the opportunity to thank M. Breguet for the courtesy which he had extended to him (the speaker) when he went through his works.

The CHAIRMAN translated some of M. Breguet's remarks, in which he explained that he was once of Mr. Handley Page's opinion that six tons was the limit at which the weight grew so fast that the area could not be expected to bear it profitably. He had proposed a complete departure in the type of construction, which, although it had not yet actually been put into being, he thought would

get rid of the difficulty of the relation of weight to wing surface. He did not claim as an invention at all, but he had made calculations by which, using the thick wing type of machine, burying the engine and load in the wings, and distributing them carefully along the wings, on a 50-ton machine, he hoped to be able to arrive at much the same wing loading and power loading as would be obtained on a smaller craft of 2 or 3 tons. The wings would be 7ft. thick.

A hearty vote of thanks to M. Breguet concluded the proceedings.

NOTES ON M. BREGUET'S PAPER.

Contributed by Captain W. H. SAYERS: I think it is most important and most encouraging to hear so very high an authority as M. Breguet expressing the opinion that very great improvements in the aerodynamic qualities of the aeroplane are not merely desirable, but are also possible. The data given in his Paper are conclusive proof—if proof be needed—of the value of any great improvement in the “fineness”—or in usual English terms—the L/D ratio of aeroplanes.

The figures as to costs, etc., given in the Paper relate to French practice and are not directly applicable to British conditions. In certain respects I think British aircraft constructors may rightly claim that they can improve on those figures both aerodynamically and in the equally important matters of the durability and longevity of their aircraft. Such criticisms do not substantially affect the justice of the author's general conclusions, with which I am in entire agreement.

I think, however, that the time has now come to question what have hitherto been regarded as the fundamental bases of aeroplane design—bases which are apparently accepted by M. Breguet for they are implied in his two equations Nos. 1 and 2.

The assumptions are that an aeroplane may be regarded as a heterogeneous assortment of surfaces and bodies, and that the forces on each of the component surfaces or bodies, taken separately, may be added up and will then represent the total of the forces on the aeroplane. Every aeroplane designer knows that these assumptions are in fact inaccurate. No isolated body of good form can be cut in two and have its resistance determined by summing the resistance or the forces on the parts.

That the resistance and lift of present aeroplanes can be determined with reasonable accuracy by this method is, I submit, evidence that present-day aircraft are aerodynamically merely a collection of unco-ordinated components. They will continue in this state for so long as designers allow themselves to be limited by a basis of design which is entirely empirical and seriously misleading. It is not true that a given wing has definite lift and drag coefficients at definite angles of attack which are independent of the body, tail and wing bracing structure to which the wing is attached. It is equally not true that the body, tail and other organs which form the complement to wings have force and resistance coefficients which are independent of the wing.

Because existing aeroplanes are so bad that they behave nearly as though these false assumptions were actually true, the designer comes to believe in them. Because he has come to believe in them, he has also come to believe that it is not possible very greatly to improve the aerodynamic efficiency of existing types of aircraft.

I am personally firmly convinced if designers can only be persuaded to forget all about the itemised resistances of the components with which they at present deal, and will regard a projected aeroplane as a single aerodynamic body, and will design it with an eye to its lines as a whole—just as they would design, say, an airship body—that it will very speedily be found possible to design a complete aeroplane having a L/D ratio of 20/1 or over, or—in M. Breguet's terms—with a “fineness” of .05 or less.

TRANSLATION OF LETTER FROM MONSIEUR LOUIS BREGUET, DATED 28th APRIL, 1922, TO THE ROYAL AERONAUTICAL SOCIETY.

Gentlemen,—I return herewith draft copy of the report of the meeting of the 6th instant, and regret that I have been unable, owing to absence, to reply earlier, as promised, to the various speakers who took part in the discussion. I very much appreciate their remarks, for which I thank them.

Replying in the first place to Mr. Handley Page, I agree with him that the Paper had in view only a part of the big problem of the future of aerial transport, but it is quite certain that while it is necessary to have good aircraft, it is equally indispensable to have as perfect a ground organisation as possible, otherwise the use of aircraft will be very uncertain, however perfect they themselves may be.

For instance, let us imagine modern navigation carried out as is actually the case with superb boats, but lacking any organisation of ports, routes, provision of buoys, lighthouses, wireless telegraphy, meteorological service, current charges, etc. The result would be practically negligible and its existence very precarious.

I did not raise this question at the meeting as I am of opinion that if from the present time until the fact is accomplished, sufficient funds are available, it is certain that excellent aerial ports, which are more easily and much more cheaply established than seaports, will rapidly come into being.

It is foreseen, however, that the aircraft destined to maintain the big international transport service will have to be of the amphibian type, and they will thus be able to utilise sea routes and have at their disposal the whole existing organisation in the big seaports throughout the world.

From carefully carried out experiments made in various laboratories I am able to state definitely that with the very good coefficients I quoted for "fineness" (indicating L/D efficiency), propeller efficiency, and minimum h.p. will certainly be realised in the near future.

I would like particularly to reply to Mr. Handley Page on the subject of large aircraft of the future. I can share his opinion that if aircraft are built on a larger scale whilst remaining geometrically similar, the ratio of wing structure weight to total weight will increase, since, all other things being equal, the weight of the wing structure, *i.e.*, spars, ribs, interplane struts, bracing, etc., increases as the surface to power $3/2$. For this reason I was for some time led to think that very large aircraft would not give results of interest, and that no comparison was possible between boats and aircraft, for even given an assured advantage to be gained by increasing the tonnage of ships, rather the opposite would obtain in increasing the size of aircraft. At the beginning of last year, however, I started to give serious thought to a type of monoplane with wings of a section deep enough to house engines, tanks and passengers. Further, by suitably distributing the loads on the wings it is easy to imagine an aircraft in which the dead weight, instead of increasing as the power $3/2$ of the area, will only increase directly proportional to the area, and under these circumstances there were no longer any disadvantages in increasing the size of the machines.

I sketched on the blackboard after the discussion how I envisaged such an aircraft. It would comprise three fuselages, one in the centre for the crew, controls, instruments, etc., while the other two on the right and left respectively of the first mentioned, and far enough apart, would be used as hulls or floats. These would contain first class cabins. Finally, the tanks and the float would be distributed inside the wings. This distribution in weights in large aircraft would obviously give them a considerable moment of inertia, but as there would be no need for "stunting," their large lateral moment of inertia would mean a high degree of stability in the air.

With big monoplanes the reduction of parasite resistance can be pushed as far as one likes, and it is to be hoped that results similar to those of plain wings furnished with the tail unit can eventually be reached. It follows that these large machines would eventually have characteristics comparable with those of large birds, and the coefficient which would be applicable to them in that case will certainly be better than those I quoted in the lecture.

To Captain Goodman Crouch I admit that certain British engines have a much longer life than 250 hours, but I ought to say that the average life of the engines used by French companies does not reach this figure.

I am entirely in agreement with Captain Goodman Crouch that in a few years aeroplanes will obtain an average life of 1,000 hours, and for this reason I have every hope of seeing engines reach 2,000 hours.

With regard to Mr. Thurston's remarks, may I say that actually there were more than 6,000 metal machines, and not 1,000, put into service during the war which are still being used.

Finally, I would like to confirm what was the basic point of my paper, *i.e.*, that technical research should be pushed forward without relaxation so that improvements already envisaged may be realised with as little delay as possible as well as those for which as yet one hardly dares to hope.

Yours, etc.,

(Signed) LOUIS BREGUET.



STRESSES IN AIRSCREWS DUE TO VARYING ENGINE TORQUE.

BY JOHN CASE, M.A., F.R.A.E.S.

1. Since the driving torque exerted by the engine is a periodic function of the time, the speed of rotation must also be periodic, which implies that the airscrew must be subjected to inertia stresses as well as to the stresses due to air forces and centrifugal forces. In the case of engines having six or more cylinders these inertia stresses will not in general be important as the cyclic variations of torque will be comparatively small. But with engines having two or three cylinders these stresses must be considered, for it will readily be seen that the bending moment due to inertia forces is such as to increase the stresses due to the air load.

It will usually be found that the speed fluctuation is small, something of the order of three or four per cent., but these changes of velocity take place in such very small intervals of time that the angular accelerations are large, and the consequent inertia stresses may also be large, as much as 40 or 50 per cent. of the stresses caused by the airload. Thus, if a propeller for a two or three-cylinder engine be designed so that the resultant stress due to the air load and the centrifugal forces approaches the safe limit, the actual stresses may be large enough to cause rupture on account of inertia. Apart from the numerical value of the stresses we must bear in mind the fact that the material will be subjected to rapidly fluctuating stresses.

The problem is complicated by the fact that the resisting torque is a function of the speed, but we know from experience, and analysis shows, that the speed variation is very small. On this assumption we can find the maximum acceleration approximately from the formula

$$\frac{d\omega}{dt} = \frac{g \text{ (max. driving torque — mean driving torque)}}{\text{Moment of inertia of rotating parts}}$$

and this will usually be sufficiently accurate for practical purposes. In the analysis which follows we shall neglect the inertia of the connecting rods and reciprocating parts.

2. General Analysis.

Let I = the moment of inertia of the airscrew and shaft about its axis, lbs. ft.²

$\omega = 2\pi n$ = the angular velocity in radians per sec.

V = the forward speed of the aeroplane, feet per sec.

T = the driving torque exerted by the engine, lbs. ft.

Q = the resisting torque exerted by the air, lbs. ft.

Now according to R. and M. 474, Q may be taken as

$$a - b (V/nP_m)^3$$

where a and b are constants, and P_m is the experimental mean pitch. For present purposes we shall take

$$Q = a - c/\omega^3$$

V being supposed constant, where

$$c = (2\pi V/P_m)^3 b$$

If the driving torque is constant and equal to T_0 , the steady speed ω_0 is given by

$$T_0 = a - c/\omega_0^3.$$

Now suppose that the torque becomes

$$T = T_0 + T_1$$

where T_1 is a function of the time, and suppose the consequent speed is

$$\omega = \omega_0 + \omega_1$$

where ω_1 is small compared with ω_0 .

The equation of motion is

$$T_0 + T_1 = I\dot{\omega}_1/g + a - c/\omega^3$$

or

$$I\dot{\omega}_1/g - (c/\omega_0^3) (1 + \omega_1/\omega_0)^{-3} = T_1 + T_0 - a \\ = T_1 - c/\omega_0^3.$$

If we neglect powers of ω_1/ω_0 above the first, this gives

$$I\dot{\omega}_1/g + 3c\omega_1/\omega_0^4 = T_1$$

or

$$\dot{\omega}_1 + 3cg\omega_1/I\omega_0^4 = gT_1/I.$$

The solution of this is

$$\omega_1 = Ce^{-\lambda t} + (ge^{-\lambda t}/I) \int^t T_1 e^{\lambda t} dt$$

where

$$\lambda = 3cg/I\omega_0^4.$$

If we count time from when $\omega_1 = 0$,

$$C = -(g/I) \int_0^0 T_1 e^{\lambda t} dt.$$

and

$$\omega_1 = ge^{-\lambda t}/I \int_0^t T_1 e^{\lambda t} dt$$

In general the integration can be performed graphically, or by expressing T_1 as a Fourier series.

The acceleration is given by

$$\dot{\omega}_1 = (g/I) [T_1 - \lambda e^{-\lambda t} \int_0^t T_1 e^{\lambda t} dt].$$

3. The Values of the Constants.

From R. and M. 474 we have

$$Q = \rho n^2 D^5 Q_c$$

where

$$K_q Q_c = 1.1042 - 0.833 (V/nP_m)^3$$

and K_q is a number such that $K_q Q_c = 1$ when $V/nP_m = 0.5$. Thus,

$$Q = (\rho n^2 D^5 / K_q) [1.1042 - 0.833 (V/nP_m)^3].$$

Hence

$$a = 1.1042 (\rho n^2 D^5 / K_q) \\ b = 0.833 (\rho n^2 D^5 / K_q) \\ c = 0.833 (2\pi V / P_m)^3 (\rho n^2 D^5 / K_q)$$

and, as above,

$$\lambda = 3cg/I\omega_0^4.$$

4. Approximate Calculations.

For two-blade propellers I is roughly $5 w B_0^2 D^3 10^{-3}$ where w is the weight per cubic foot, and B_0 is the maximum blade width.

Also

$$c = \frac{1}{2} (V/nD)^3 (D/P_m)^3 (n^5 D^5 / K_q) \text{ approximately.}$$

Now V/nD and D/P_m are both of the order of unity, and K_q is of the order of 50, so that, roughly, C is of the order of $N^5 D^5 / 100$.

Then

$$\lambda = (3g/16\pi^4 n^4) (n^5 D^5 / 100) (1000/5wB_o^2 D^3) = (3g/800w) n (D/B_o)^2.$$

For most propellers D/B_o is about 10, and g is about equal to w , numerically, so that λ is of the order of $3n/8$.

As an example consider a three-cylinder engine, and suppose T_1 expressed as a Fourier series; the dominant term will be proportionate to $\sin 3\omega_o t/4$.

So let us take

$$T_1 = \tau \sin 3\omega_o t/4.$$

In this case it is easy to show that the maximum value of the acceleration is given by

$$\dot{\omega}_1 = (g\tau/I) [(3\omega_o/4)/\sqrt{\{\lambda^2 + (3\omega_o/4)^2\}}]$$

Now $(3\omega_o/4)^2 = 22n^2$ and we have already seen that λ is of the order $3n/8$. Thus we may expect the error arising from taking the approximate expression for the acceleration to be very small.

5. Bending Moment Due to Acceleration.

Let M denote the bending moment, due to inertia forces, on a section of the blade distance r_o from the axis of rotation. Then

$$M = \int_{r_o}^R r \dot{\omega} (r - r_o) dm$$

where dm is the mass of the blade element at radius r , and R is the extreme radius of the airscrew.

Let $A = aB_o^2$ = area of the cross section of the blade at radius r , where

B_o = the maximum blade width.

w = the weight of the material per cubic foot.

Then

$$M = (w/g) B_o^2 \dot{\omega}_1 \int_{r_o}^R ar (r - r_o) dr$$

and the integration is performed graphically.

The component of this about an axis parallel to the chord of the section is $M \sin \theta$, where θ is the pitch angle for the section under consideration. It is this component which must be taken in estimating the stresses.

6. **Example.**—Consider the case of a three-cylinder engine for which the torque is given approximately by

$$T = 400 - 750 \sin (3\omega_o t/4)$$

and $\omega_o = 180$ radians/sec.

$$I = 22.5 \text{ lbs. ft.}^2.$$

$$\lambda = 7.$$

We find

$$\omega_1 = 0.0587 (7 \sin 135t - 135 \cos 135t)$$

$$\omega_1 = 7.927 (7 \cos 135t + 135 \sin 135t)$$

and the maximum value is

$$(\dot{\omega}_1)_{\max} = 7.95 \sqrt{7^2 + 135^2} = 1072.$$

The approximate formula would give 1074 instead of 1072. Thus the maximum angular velocity range is only 7.95 radians per second, or about 4.3 per cent. and the maximum acceleration is 1070 radians per second per second. In the case under consideration this will cause an increase of compressive stress of about 40 per cent. at a section where $r/D = 0.2$.



ON RESEARCH AND OTHER MATTERS.

BY LIEUT.-COL. S. HECKSTALL SMITH, F.R.A.E.S.

If the thought of another war troubles you, then don't read this article. If you would rather say to yourself as the Secretary of State said to the Air Conference, "There won't be another war for ten years, so why worry?" then no doubt you will think with him that it is better to let other nations have all the bother and expense of trying to advance; after all, we are jolly fine fellows and can soon pick up. If, on the other hand, you have imagination which gives you a nasty queasy sensation when you think of what might be, then perhaps the following notes, albeit disjointed and mostly stale, may at least conjure up in you thoughts of your own on the subject. This is all that is needed to help our advancement in the air—the stimulation of spoken and written thoughts by the British nation, for if every taxpayer in the British Empire says "Air Force," then the Press and Parliament will say it too.

In a terse letter to the "Times," our Chairman, Lieut.-Col. O'Gorman, C.B., pointed out the utter absurdity of the present position with regard to scientific research. I doubt with him that this is so much due to lack of money as it is to lack of imagination, for, as Colonel O'Gorman pointed out, it is not the *amount* of money which is being spent on the air, but the *percentage* which is being spent on research. It amounts to almost nothing. It has always been the same, and therefore there must be some reason for it.

I think, after many years of close contact with the problem, that the reason is this. The instigation and approval of research programmes are controlled by the wrong people. When I first came in touch with air research work we were controlled by the War Office—by soldiers. Now I am not going to say one word except in the highest admiration of the War Office and the Staff, but what I do suggest is that the better the War Office and the better the soldier (or sailor), the worse they are, *ipso facto*, for research. The great general is a man who fights with the weapons which are available, and uses them to the best advantage. If the fighter, no matter of what sort, said "I could beat this enemy if only I had thicker armour, longer range guns, poison gas, periscopes, paravanes, or what-not," then I say that such a fighter is no use.

It is not of such stuff that our Army and Navy are made.

On the other hand, it matters not one jot if the scientist who invented all these things should tremble at the knees at the sound of a gun!

The scientist need not be a fighter, able to do battle, in order to make war more terrible; all he need know is the broad principle of all wars, battles, or individual fights, which is to deliver a "decisive blow," and to have an analysis of the value of "blows," which are, I think, as follow:—

1. The weight.
2. The distance delivered.
3. The accuracy of aim.
4. The unexpectedness.
5. The speed of delivery.
6. Immunity of the deliverer.

The first pre-historic man who crouched behind a bush with a club, instead of using his fists in the open, used all the above points to his advantage. The man with the rock in a sling beat him because he improved on 2, 4, 5 and 6. The modern naval gun is better still on all points; and the aeroplane with bombs has again advanced.

The scientist can understand and appreciate these things, and give relative values to the items which are, of course, variable with the weapon used; thus with guns, weight of the blow with distance and accuracy are probably among the most important; whereas with poison gas, given the volume (or weight equivalent), the unexpectedness might be the greater value. It is entirely on the scientific advancement of the above points that the decisiveness of blows in future warfare will depend. It wasn't the well-known high excellence of the Scotch marine engineer that produced the marine turbine; and it is still less the high excellence of the British admiral that produced the submarine, which is merely an unfortunate outcome of the utilisation of electric energy discovered by scientific men. The soldier and the sailor have got to understand these horrid new weapons; they have, by use, got to develop and improve them and make them practical, with the help of engineers; but to devise them is to make practical men into dreamers, and a fighting man who dreams, well, he doesn't!

Now of all new developments there is none with such vast possibilities in war as aircraft. Compare them with any other blow-delivery weapons on the above six points! The weight of the blow?—there is no weapon which will deliver as much. Distance?—ten or fifteen times greater over land. Accuracy?—perhaps at present there may be some controversy as to this, but the possibility of development points to considerable accuracy. Unexpectedness?—nothing can compare. A hostile country could declare war with a bombing fleet, arriving over the enemy's country out of sight. The "three-dimension" movement of aircraft puts them far ahead on this most important point. Speed of delivery?—Again, over long distances on land or sea there is nothing to compare. Immunity?—Again I should say the advantage is with aircraft, landcraft coming next in order, and surface seacraft last, since they can be attacked from above, below and sideways, while offering a slower moving and larger target surface with less vision of the enemy or power to hide.

Another point might be added, and that is the cost of the blow in ton-miles. Here, I must confess, I have no data to work on, but it is an interesting speculation well worth arriving at. This much, however, one can say. Suppose it was considered a decisive blow to drop 1,000 tons of explosives on a capital city, 300 miles away, 50 miles from the coast, and deliver the blow within 24 hours of starting operations. There is only one way to do so—by air. The Army plus the Navy could do it, but not in 24 hours; so the 4th and 5th points of the "blow" would be lost, and with the loss of these points the whole effectiveness of the "blow" would disappear.

The initial cost of the weapons by air for this would not be more than twelve millions, whereas the Army plus the Navy—even if they could do such an operation—would cost ten or twenty times that amount. Yet, one is told, we cannot afford an Air Force!

There can be only one possible reason for this, and that is that even now the value of research is not understood. One great difficulty about it being understood is that the non-scientifically-trained person cannot understand the working of the mind of the true scientific research worker. They talk a different language. To get a Government finance branch to put up money for a tangible thing which one can see and touch is hard enough, but to put up money for the intangible thing which a visionary scientist may suggest as a vague possibility without any promise of finality or value, if and when arrived at, seems to the finance branch an absurdity. This wretched scientist cannot even be relied on to stick to his original ideas. He may start on a non-ferrous alloy and end up by making a new explosive! Such a fellow is not to be financed. He may demand expensive apparatus, and when at the end of two years you ask him what he has done, he may show you some perfectly incomprehensible data on a dirty half-sheet of notepaper, or produce a few cheap-looking funny-shaped glass tubes with odd bits of metal and wire stuck on of no apparent value, and then turn

round and tell you "he is hopeful that he has accidentally hit on an interesting phenomenon."

So the financier shakes his head, vainly trying to understand it all. And yet, as a matter of course, he will use telegrams, telephones, wireless, or amuse himself with photography, kinemas, or take advantage of X-rays, electric trains, and will probably be the first to send his mails by air *when* they can be sent regularly, little thinking that none of these things would have been his for the asking but for the scientific, self-sacrificing researches of men of just this calibre! The man of science creates the wealth by extracting the secrets from nature and pointing out their use, the engineer develops them, and the commercial man takes the profits. The Press point out how they were the first to understand the whole thing, and the public, the politicians and the lawyers combine to dissipate the wealth as quickly as possible. Charles Kingsley wrote, many years ago, of what he called the "Aristocracy of Science." "What else," he says, speaking of this aristocracy, "what else, unless there be left in the nation, in society, as the salt of the land, to keep it from rotting, a sufficient number of wise men to form a true aristocracy, an aristocracy of sound and rational science? If they be strong enough (and they are growing stronger day by day over the civilised world), on them will the future of the world mainly depend. They will rule, and will act, cautiously, we may hope, and modestly, and charitably, because in learning true knowledge they will have learnt also their own ignorance, and the vastness and complexity and mystery of nature.

"But will they be able to rule? They will be able to act because they have taken the trouble to learn the facts and laws of nature. They will rule; and their rule, if true to themselves, will be one of health and wealth and peace, of prudence and of justice. For they alone will be able to wield for the benefit of man the brute forces of nature; because they alone will have stooped to conquer nature by obeying her."

The alternative to supporting the scientist was pointed out by Charles Kingsley. He goes on: "The aristocracy of mere 'order,' which means organised brute force and military despotism. And after that, what can come, save anarchy and decay and social death?" It is the scientist as Charles Kingsley saw him that we should support, for surely the sooner the world realises the foul terrors of future war, the sooner will wars end! It is in our half-developed state that peril lies; not even half-developed as far as the air is concerned. It is safer in the air to be a hawk than a sparrow. One cannot think yet the world is rid of hawks.

I find it is forgotten by the "man in the street" that on the outbreak of war in 1914 aircraft played no part in attack; in fact, it was not until the end of the war that we were in any sort of shape to bomb on a small scale with heavy bombs. As a real weapon to deliver decisive blows, aircraft did not exist in the war at all, therefore no deduction can be made from the war on this subject. What has to be decided is the minimum effective air force to deliver a blow with sufficient weight at a sufficient distance, with unexpectedness, secrecy and suddenness, with accuracy, and at a speed to make the blow decisive, at the same time making our air fleet as immune as possible.

Here is a field for research; almost every word of my "conditions" opens up a vast field of separate but closely co-ordinated work. The size and plan of the aeroplane to take the most effective and economical form of bomb; the horse-power required, whether in one or more engines, will affect this, as will the petrol (or heavy oil?) consumption. The type of bombs, whether explosive or gas, or both; secrecy will depend on the height of flying, which involves the speedy development of super-charged engines and variable pitching of airscrews, together with research into metals, cooling, and fuel, all of which again tend to compromise the original plan or dimensions. The accuracy of aim covers

a very wide field, including the view of the observer, his ability to direct the aeroplane vertically over the object; the measurements of speed and height; the accuracy of aim when all these points are known, as well as navigation at great altitudes to the objectives. Further, the general weight and area of the "blow" depends on organised formations of the fleet. What a tremendous range of research we have here! High flying, with the engine difficulty and protection of the crew from cold and lack of oxygen; navigation through clouds in formation, which is essentially a matter of stability in the aircraft accompanied by accurate instruments—the compass, the turn indicator, the speed recorder, the height recorder, and the air mileage indicator, as well as wireless control of the formation of flights.

It must be understood that none of these instruments are perfect; all are possibly perfectable. But the use of them, the training with them, and the organisation are all wanting. The "unexpectedness"; this might at first seem a matter of pure military organisation of mobilisation stores, charts, equipment and skilled handling. It no doubt is, but is it not more? If we are to depend on a sudden attack, or counter-attack, at the very outset of the next war—as General Groves has so very clearly and ably pointed out we shall have to—then is it not a matter of military importance to see that our commercial air fleet will meet, to the best advantage, some of the points required to "deliver the blow"?

It does not follow that a good commercial aeroplane will make a good bomber; the conditions are utterly different. The commercial machine must first be economical, safe, and, if a passenger machine, comfortable. It has to "get off" every day, or several times a day, with full load, and still more important, land with full load; and there must be no undue risk. On the other hand, the bomber has to "get off" occasionally as a war risk with full load and land without it.

If, therefore, the commercial fleet is to be used in war—and everyone seems clear that it must—then it may be necessary to compromise the design of commercial machines, even at the expense of economy in transport, and loss of efficiency, to make these machines suitable for both purposes; such loss should therefore be made good by the Government in order to gain military advantage at the least expense in the long run. With these difficulties, the need for research and full-scale experiments will be obvious, the co-operation of all concerned essential.

The "speed of delivery"; this must depend on the size of the air force, its readiness, and the capabilities of its machines, personnel and staff. On the size because it is useless to deliver a swift blow without sufficient "weight," just as the weight is useless without the "aim" being good, and the value of the aim being modified if not "unexpected" so that the other fellow has time to dodge.

On the final question of the "immunity of the deliverer," it is difficult to predict as to whether the bombing fleet should be protected by other fighting machines or should rely on their own fighting qualities, or capabilities to dodge, or whether artificial clouds would protect them if made by themselves or other special accompanying machines. The Air Force, like the Navy, will no doubt learn all such tactics on manœuvres.

If commercial aircraft are to play any part in war, then the sooner it is decided what part or parts, the more likely they are to become effective and the more value to the nation will the Government subsidy for commercial aircraft possess.

At the present time there is a sort of apologetic feeling all round about subsidies, but I am sure this would disappear if the military value and postal value of commercial aircraft were made full use of; for then, and only then, will

the taxpayer appreciate that he is getting something for his money. To subsidise air lines to take American tourists to Paris or bring frocks made in Paris to London or cut flowers from Holland to sell in Covent Garden cannot be expected to appeal to the British public; but to deliver his mails to India, Australia, in double or quadruple quick time and thus increase the possibilities of overseas trade is within his understanding, as is also the value of defending his home.

Everyone pays for fire insurance, but most of us prefer also to pay for the fire brigade plus the water rate. And it is just because we are now without their equivalents in home defence that the public feel worried, or ought to.

The development of Royal Mail (Royal Air Force Reserve) Fleets is of the greatest importance to our safety. We want to see the Blue Ensign of the sea flying well above it, as well as on it. We are still a long way off making the Red Ensign a commercial success in the air, and it is just for this reason that I am offering these few notes on the whole subject. Not because I have anything new to say. It is not necessary to say anything new, or suggest any novelty, but only to repeat again and again the old expression of hope that research into such matters of national importance will be regarded as having importance, not impotence. For there is no doubt the power to create is available, the fertility of brains is never lacking; it is only the uniting of science and practice that is so difficult, that one would think they were things apart, never to be joined in wedlock, lest they should produce an offspring in the nature of a freak!

Yet, where have we got to in aircraft? An aeroplane is still a thing of wood and wire and linen and string. Had we the knowledge we might have (by research) on light alloys, I doubt not that the whole structure would change; in fact, if we knew the truth, we might find it had already changed—abroad.

If such a change as this came, it would alter the whole scheme of aircraft construction. The furniture-maker, piano-maker, joiner, carpenter and upholsterer would disappear, and the adequacy of the metal-worker to meet war demands would have to be considered, as well as the supply of raw materials, sheets and tubes, with the tools, jigs, fixtures and the like. It is clear that if aeroplanes had been all-metal when war came in 1914 we should have been in poor shape to meet the demand. It behoves us, therefore, not only to develop our fleets, but to consider their multiplication on a rapid basis in another war.

The air development will make our island a very different place in the next war. What about food supplies, supplies of raw materials? The merchant vessels will be an easy prey to hostile aircraft. What about the supply of oil and petrol even for our air fleets? I said these things made one feel queasy, but the shortage of food by the sinking of supply ships brings it home even more than an air raid by a "blow" of 1,000 tons of explosives (or poison gas) on London in 24 hours, delivered with "accuracy" and "unexpectedness." It seems almost worth while to spend a bit to counter this. I wonder if we shall? It is not so much, I expect, that we shall not spend as whether we shall spend in the right direction.

Quite probably the Army, Navy and Air Force have considered my six points of the "decisive blow" years ago, and we laymen don't know what they have got up their sleeves; all the same, there were a few times during the war between 1914 and 1918 when it took us all our time to cope with new things under heading No. 4, and then, and not until then, did the scientist come into his own. Personally, one would like to see him come in sooner; it's all right, we know, but these "jolly near shaves" affect the colour of one's beard. I'm all for calling in the doctor in good time, especially the doctor of science, in a matter which, without any shadow of doubt, is one of the most scientific that man has ever faced, and also the most important, as his life and future prosperity depend on lack of errors.

The ideals of true research are so obscure to the average non-technical man that the fact that there is no real research is frequently camouflaged by the flaunting of some interesting and important piece of experimentation which completely misleads the unwary into the belief that much is being done.

Experimentation is *not* research; it is a necessary adjunct to it, but should not be confused with either the work of research or the workers. A research into a new dye and an experiment in commercial dyeing require different types of brains and different education. Both are equally important; the second is not research, but may well affect the research, call on it, and help it. Thus, in looking into the amount which is actually being spent, the most important features to consider are: The ability of the Chief, by his past history, training and achievements, to Create, Control and Co-ordinate (three C's) true research; the Facilities given him, and the Freedom he has to select a competent staff, and the Financial resources he has to pay them (three F's).

Let the public satisfy themselves on these points and on the fact that such research will be followed by thorough experimentation, and this again by quantitative practice; then, and not till then, will the "queasy" feeling subside, for the doctor of science will inspire in the patient public that confidence which will enable the public to say, "Every day and in every way we are getting safer and safer."



THE IMPORTANCE OF LOW WEIGHT PER B.H.P. AND LOW FUEL CONSUMPTION PER B.H.P. OF THE POWER PLANT FOR AEROPLANES.

BY A. L. ROWLEDGE.

The power plant of an aeroplane is usually designed by a different person situated in a different works from the aeroplane designer, yet it is essential that both should understand something of each other's work, if the best result is to be attained. It is of the first importance that the engine designer should have a clear idea of the value to the aeroplane designer attaching to low weight per b.h.p. and low fuel consumption per b.h.p., when considering a new design or comparing the merits of existing ones.

These notes are written entirely from the point of view of the engineer providing the power plant, and as a basis of discussion it is assumed that aeroplanes for various purposes of equally skilled design will have the same performance if the total flying weight per b.h.p. is the same.

We will divide up the weights of the machine as follows :—

W = Total flying weight.

A = Total weight of the aeroplane structure.

E = Total weight of the power plant (less fuel and tanks).

F = Total weight of the fuel and tanks.

L = Useful load.

It is intended that the engine weight shall include everything belonging to the engine, including engine supports and cowling, but not the fuel and tanks, which are taken as a separate item. The aeroplane structure represents everything belonging to the aeroplane (not included in one of the other items) including crew.

We will use capital letters for the total quantities, and small letters for the quantities per b.h.p., and in addition we will let the letter "t" represent time in hours, and "k" represent the value of the structure weight as a fraction of the total flying weight. The fraction varies in value of course with different types of machine, but probably the adoption of a constant is justifiable for our purpose.

Then

$$W = A + E + F + L$$

$$L = wBHP - eBHP - aBHP - ftBHP$$

$$l = w - e - a - ft$$

$$= w - e - kw - ft$$

$$= (1 - k)w - e - ft.$$

$$\text{B.H.P. to carry 1lb. useful load} = \frac{1}{(1 - k)w - e - ft}$$

It would perhaps be interesting to take some values for the various quantities, and to plot curves showing possible differences in performance.

We will assume for our purpose that $k = .32$ and that $f = .65$.

Diagram Fig. 1 shows the b.h.p. per lb. of useful load required when the time of flight is four hours. Three lines are shown on this curve for machines having total flying weight per b.h.p. of 10, 15 and 20lbs. respectively. The dotted curves show the result of a saving of .1lb. per b.h.p. on fuel consumption.

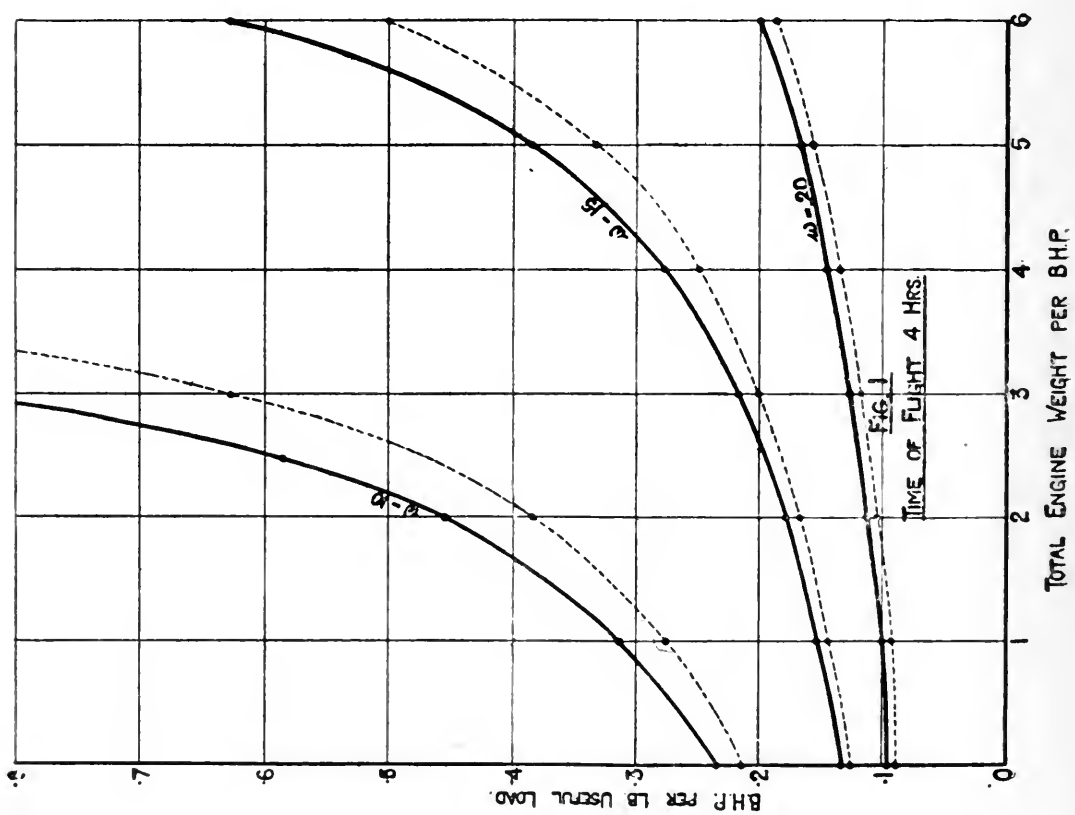
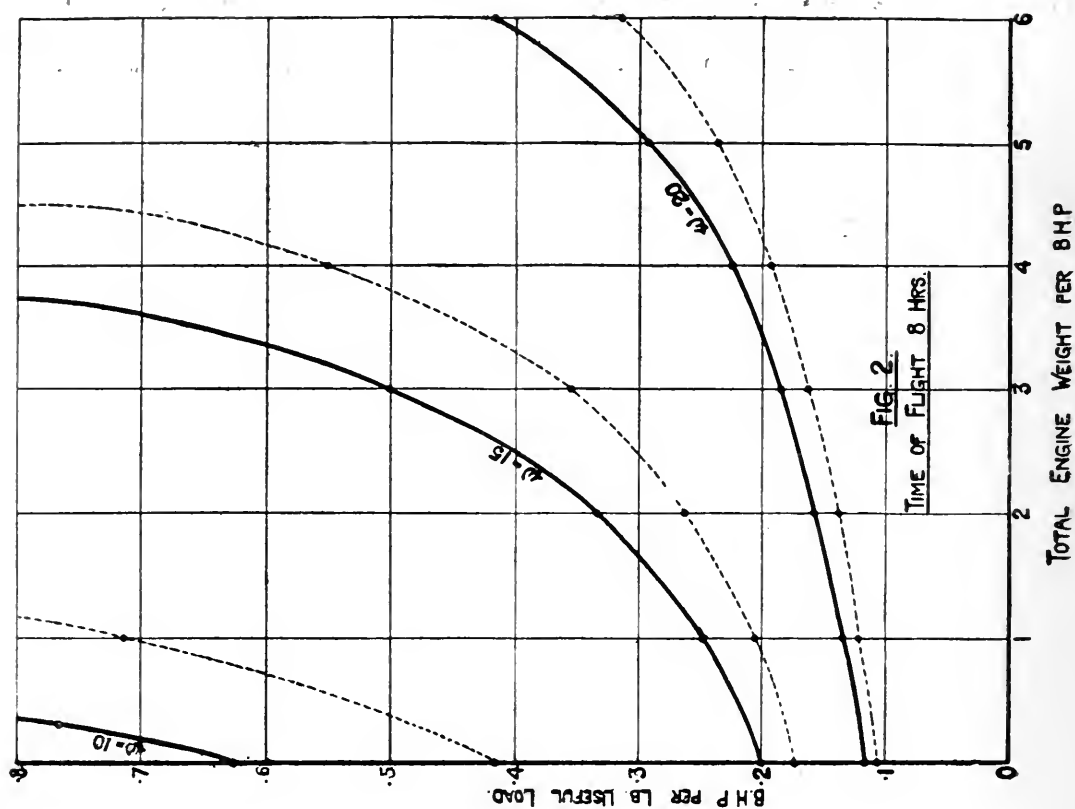


Diagram Fig. 2 assumes the same conditions except that the time of flight is now eight hours.

The load of petrol carried is taken on normal engine b.h.p. As the machine must be capable of carrying sufficient fuel for bad weather conditions it is thought that this is a satisfactory basis.

It is obvious at once from these curves that the importance of saving in weight per b.h.p. either in the engine or by fuel consumption varies very much with the type of machine. Commercial machines appear to be satisfactory with a flying weight of approximately 15lbs. per b.h.p., and apparently this figure cannot be very much exceeded owing to the necessity for a good take off. With long-distance bombing machines greater risks are taken. The curves show very clearly the impossibility of building a machine with high performance and a heavy engine. The usual weight of the power plant in commercial machines to-day (less fuel and tanks) varies between 3 and 5lbs. per b.h.p.

If we assume a machine is to be built to carry 1,000lbs. useful load, that it is a commercial machine, and that the desired performance is represented by a total flying weight of 15lbs. per b.h.p., then if the power plant weighs 3lbs. per b.h.p. and the desired maximum duration of flight is to be four hours, an engine of 218 b.h.p. will be required, and the weight of the aeroplane structure will be 1,046lbs. If the power plant weighs 5lbs. per b.h.p. the b.h.p. required will increase to 374 and the weight of the aeroplane structure to 1,795lbs. It is unnecessary to point out how the loss in efficiency will increase both the first cost and running costs.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

Dayton, Ohio,

June 22nd, 1922.

DEAR SIR,—In Colonel Ogilvie's Wilbur Wright Lecture, he expresses regret that the scientific laboratory work of the Wright Brothers back in 1902 and 1903 had not been published.

During my recent visit to Dayton I have had the opportunity of referring to the correspondence of the Wright Brothers at this period and it will, no doubt, be interesting to members of the Society to know that although the tables of the scientific laboratory experiments were not published, they were freely given at that time to several people who were interested in attempts to achieve mechanical flight. Mr. Chanute and Dr. Spratt had both full tables given to them in 1902 and 1903. Professor Marvin, now Chief of the United States Weather Bureau, and Dr. Zahm also received some of the tables at this time. Probably the fact that there were very few persons who were known to be interested in flight at that time, accounts for the comparatively small number of people who received these tables. It was only after the Wright Brothers had spent some thousands of pounds on their experiments, and it became necessary for them to recover this amount out of the invention, that further particulars of the invention were withheld pending negotiations for placing the machine on the market, and obtaining a modest reward for the risk and the work which they had successfully completed.

Very truly yours,

(Signed) GRIFFITH BREWER.

REVIEW.

14,000 Miles Through the Air. Sir Ross Smith.

This little book will make its appeal to thoughtful people, in that its story, ostensibly one of heroic enterprise, is brimming with promise of the future. Sir Ross Smith, in the space of 136 pages, gives us his "Pilgrim's Progress." How in just less than 28 days he flew half round the world; how he and his gallant crew climbed the Hill Difficulty; how across mountain and swamp, ocean and desert, through snow blizzard, through intense heat, he flew triumphantly home, cannot fail to quicken the imagination. The book is well illustrated with photographs, with the exception that it is a little difficult to see the relation of one or two of them to the text. The narrative is warm, well sustained, and not without a native humour; here and there by lack of a literary sense Sir Ross comes dangerously near to pathos, but his obvious sincerity compels the reader to forgive him, for he is a man of action rather than of letters. To the procrastinator his book is indeed a lesson. Again and again he pushed on under terrible conditions, after events proving that had he waited, fast flooding aerodromes would have held him prisoner. No less is it a beacon to all who set out on great quests. The minute preparations beforehand, the simple unison between man and machine without which neither can rise to perfection, the attainment of the physical fitness of both, were all implicit in the supreme moment of landing in Australia.

Perhaps it is those who make it their profession to fly that his story will touch most nearly. Yet what Sir Ross Smith, his brother and his two sergeant mechanics performed on an almost uncharted airway as a feat of endurance, will one day be a commonplace. Romance will become cold fact. Mankind will be apt to forget what it cost these pioneers of the air, who first linked up the Empire. In comfortable, swift, stable air liners, provided with adequate means of navigation and with wireless, they will scarcely remember the pioneer pilots, who were chilled and lonely, deafened with unsilenced engines, who ceaselessly reiterated the nervous routine of glancing from instrument to instrument in momentary fear lest a flickering pointer should convey the dread message that something vital had gone amiss. And Sir Ross Smith faced that ordeal, so he tells us, hour after hour, when flying over country that would yield not one friendly spot to land on for hundreds of miles. How natural the warm glow of human companionship and cheery welcomes where he paused en route! Even then he and his crew did not relax. Invitations to enjoy themselves were showered on them, much to their embarrassment; yet always they saw to their beloved engines, insisted on manhandling every pint of petrol into their tanks so that no dirt should enter, sacrificed their short sleep to hold the Vimy down when storms raged through the night, set out again if it were possible with the first light. From beginning to end it was a race against time; in spite of all that human forethought could devise it still remained a colossal hazard. They won, because sheer grit deserved them to win.

And now in his strong and vigorous youth the author has met with an untimely end. He died at the helm of his aeroplane, with his hands upon the controls. Can there be any doubt that his spirit rests

"Among the chosen few,
Among the very brave, the very true?"



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All communications should be addressed to the Editor.

No. 141.

SEPTEMBER, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Lectures.

Arrangements have been made for advance proofs of all lectures of the coming Session to be supplied on payment of 6d. each lecture or 2s. 6d. for the series of eleven (excluding the Juvenile Lecture). A complete list of the lectures together with an order form will be found among the advertisement pages. The first two lectures, on October 5th and 19th, will take place at the United Service Institution, Whitehall, S.W.1. The remainder will be held as usual at the Royal Society of Arts, John Street, Adelphi. All lectures commence at 5.30 p.m. except where otherwise stated.

Pilcher Prize.

The Council have awarded the Pilcher Memorial Prize for Students to Mr. S. H. Evans for his paper on "Some Notes on Commercial Aircraft" read at the Students' meeting of March 23rd, 1922.

Examinations.

The first examination for Associate Fellowship held under the new regulations will take place in the Society's Library on Monday (Part I.) and Tuesday (Part II.), September 25th and 26th.

Students' Section.

The following provisional programme for the first half of the next session of Students' meetings has been arranged:—

- Oct. 12th, 6.45 p.m. Annual Meeting and Election of Officers.
7.30 p.m. Inaugural Address by Dr. A. J. Sutton Pippard.
Chairman—Lieut.-Col. W. Lockwood Marsh. (This meeting is open to all members of the Society.)
- Nov. 9th, 7.30 p.m. Mr. H. C. Brown, "Airships." Chairman—Lieut.-Col. W. Lockwood Marsh.
- Nov. 23rd, 7.30 p.m. Mr. G. R. Irvine, "Some Practical Points in Aero Engine Design and Construction." Chairman—Major-General Sir W. S. Brancker.
- Dec. 14th, 7.30 p.m. Mr. A. P. Rowe, "Navigation of Aircraft." Chairman—Sir A. Whitten Brown.

All meetings are held in the Society's Library.

W. LOCKWOOD MARSH, *Secretary.*

PROCEEDINGS.

TENTH MEETING, 57th SESSION.

A meeting of the Society was held at the Royal Society of Arts, Adelphi, London, on Thursday, March 16th, 1922, the Chairman, Lieutenant-Colonel M. O'Gorman, in the chair.

The CHAIRMAN introduced Dr. V. E. Pullin (Director of Radiological Research, Royal Arsenal, Woolwich), who read a paper on "Radiological Inspection Work." Although, said the Chairman, Dr. Pullin put forward no claim to being a specialist in aeronautical matters, the investigation of the inside of materials would interest the members of the Society extremely. They would find the Paper very suggestive, and it might lead to developments in the direction of aeronautical safety, towards which they were striving, with every promise of success. He then called upon Dr. Pullin to read his Paper* on

RADIOLOGICAL INSPECTION WORK.

The object of my lecture is to show the present position of radiology with regard to its usefulness in affording a means of inspection of various materials and more especially the materials and parts used in aeroplane construction. At the present time a good deal is written about X-rays and we who are working on the subject have to combat two extreme points of view—on the one hand the popular idea that X-rays can penetrate anything and on the other the idea that the whole subject is all very well as a laboratory piece of apparatus, in other words, a toy, but of no value whatever to the practical man.

I want to-night to show you exactly what X-rays are capable of doing now, what modern apparatus and technique can achieve and also what the limitations are and how far it will be possible for research to overcome them within a reasonable time. In the first place I will give you a general sketch of the activities of the Radiological Laboratory in the Research Department at Woolwich. The whole idea of radiological research there is to apply radiology as far as possible in every direction to the needs of the fighting services. We are not concerned at all with pure research for its own sake and only undertake such problems when they form a very definite means towards a practical service end.

The apparatus required for inspection purposes, which forms one of the main directions of work of this laboratory, is as follows:—

1. An X-ray tube capable of a heavy output of rays and designed to run for long periods.
2. A convenient high tension electrical transformer with a suitable rectifying device. For general inspection or factory use the installation should be portable, and perhaps most important of all, the whole apparatus must be absolutely safe both as regards X-ray and electrical dangers. Such a set, to have a maximum value, must also possess a simplicity of control in order that it may be put into the hands of comparatively unskilled workers. Fig. 1 illustrates such a set, which was designed for a specific factory purpose.

To consider now the general question of modern apparatus. It is not my purpose to discuss in any way to-night the physics of X-rays, I shall merely refer

* Synopsis only given.

to what are the essential pieces of apparatus required. A source of high tension uni-directional current, an X-ray tube, protection for the operator and also a method of registering the rays after passing through the specimen. For our present purpose we need consider only the high tension transformer as a source of high tension current, and as it may be taken generally that the penetrating power of the X-rays produced depends entirely on the voltage which is applied to the tube it is clear that transformer design affords a very large field for research in general radiology.

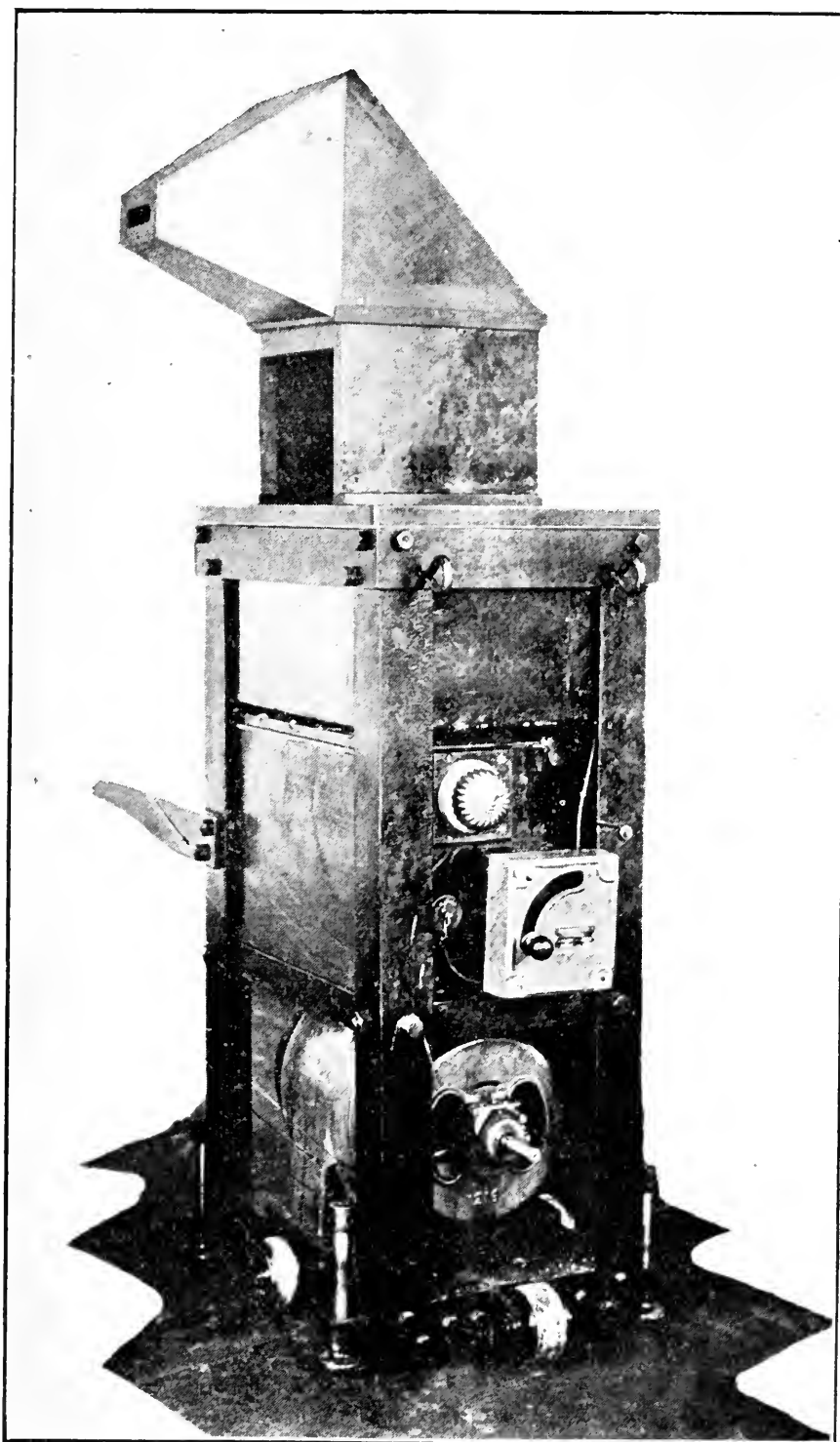


FIG. 1.

Portable X-ray apparatus for factory or inspection use.

For example, a transformer designed to give an (R.M.S.) voltage of 150,000 should, all other things being equal, enable us to penetrate three inches of steel and with modern technique should enable us to detect a flaw of about 1/64th of an inch. The current required for the operation of an X-ray tube must be uni-directional. It is therefore necessary to provide a device which shall rectify the alternating current delivered by the transformer. Here again is another subject for research.

The next and most important piece of apparatus is, of course, the X-ray tube itself, and if I had the time it would be possible to say quite a lot on this subject. However, I only propose to ask you to remember that the best type of tube for the work under consideration is that which is known as the hot cathode type in which the production of X-rays depends upon the emission of electrons from an incandescent filament. The great advantage of such a tube is that it is capable of very accurate control and it is more or less consistent in its performance.

The next point for consideration in an X-ray installation for inspection work is that of protection for the operator and workers from X-ray and allied dangers. In addition to the danger of shocks the presence of high tension electricity in the atmosphere is associated with certain obscure physiological conditions which may prove very harmful. It is therefore essential that all high tension apparatus should be carefully protected, and further that any room in which an X-ray installation is continually operated should be thoroughly well ventilated.

Regarding now the dangers due to X-rays, these are of the greatest importance because the physiological effect of the ray is not by any means understood. It is known that one type of X-radiation produces skin disease which does sometimes manifest itself in a severe form, but fortunately this particular form of radiation may be eliminated by a suitable system of screening.

There is another type of radiation which is produced at the same time which will penetrate a considerable thickness of almost any protective material and it is probable that these rays have a much more serious physiological effect, probably on the blood and deeper tissues. The problem is then to provide protection for the operator from the whole of this radiation.

The next item on the list of apparatus is perhaps one of the most important from the point of view of the practical man. It is the method of registering the rays. It is not necessary to refer here to the photographic method which, although valuable when examining certain of the heavier specimens, does not apply when considering the question of routine examination which has proved of so much service in aircraft construction. In this respect we need only consider the fluorescent screen which forms a means of rapid visual examination. The visual examination depends roughly on three factors:—

1. The screen itself.
2. The optical arrangement of the installation.
3. The physiological characteristics of the observer.

The choice of screen is important. X-ray screens in general are made of a coating of granular fluorescent substance on card or other material.

The fluorescent substance generally used is platino-cyanide of barium. Another cheaper but efficient type of screen is now made which is coated with a different fluorescent material and is known commercially as a white salt screen. The points about the choice of screen for this work are:—

1. Luminosity under the influence of the rays.
2. Contrast.
3. Granularity.
4. Fatigue.

Fluorescent screens vary considerably on each of these points. For instance, with regard to luminosity a difference of as much as 25 per cent. was observed

between one commercial screen and another. With regard to a comparison between the two types of screen referred to, there is very little to choose. Perhaps in general a platinum screen is superior, but this is more than compensated for by the far smaller cost of the white salt screen. The construction of the optical arrangements is important. Examination should always be made indirectly, that is, by means of a mirror. All light should be excluded as far as possible as the presence of stray light detracts enormously from the efficiency of observation. The physiological characteristics of the observer vary considerably. One man may prove to be an excellent observer while another may fail almost entirely to appre-

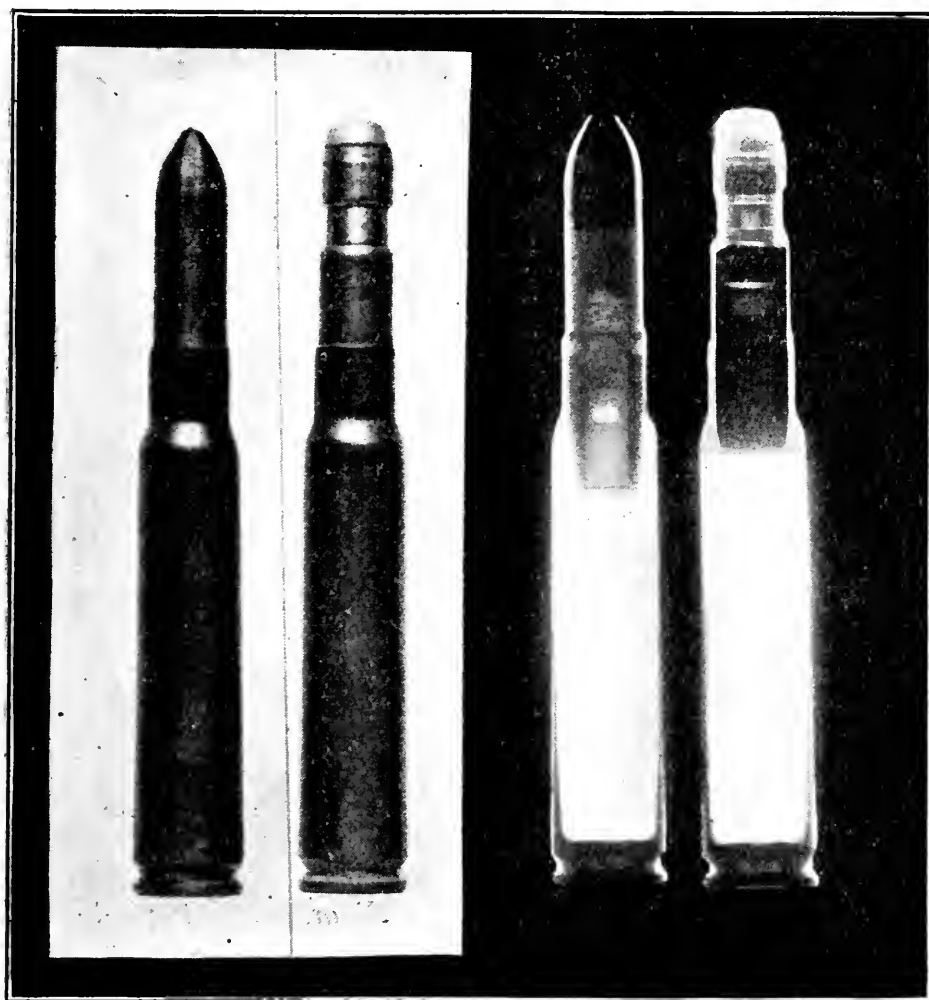


FIG. 2.

German explosive ammunition. Left, photograph; right, radiograph.

ciate fine detail. The eye may to a certain extent be rendered more sensitive by remaining for about five to ten minutes in the dark, but of course visual acuity varies considerably in different people. A good observer must possess an acute sense of contrast in illumination. It is a well-known fact that it is much easier to appreciate such contrast when illumination is brilliant than when it is feeble. Consequently we must aim at brilliant illumination of the screen, but this means a heavy current through the X-ray tube and at the present time really brilliant illumination of the screen is not possible when examining metal structures.

The research is proceeding along the lines I have indicated and progress in every direction is to be looked for, but at the same time the use of X-rays at the present state of development is certainly not properly appreciated. This applies more especially to you who are engaged in manufacture and inspection of aircraft which by reason of the lightness of the parts renders the radiological examination

comparatively simple. The one important essential is that skilled attention shall be devoted to suitable design of the installations.

Another point of noteworthy importance is that radiological examination is absolutely reliable. The enormous importance that attaches to the security, workmanship and materials of an aeroplane, a matter always of life and death, demands that no method of inspection which adds or may add so much to the security of the structure as a whole can be ignored without the fullest possible investigation.

Slides were then shown illustrating radiological inspection work.*

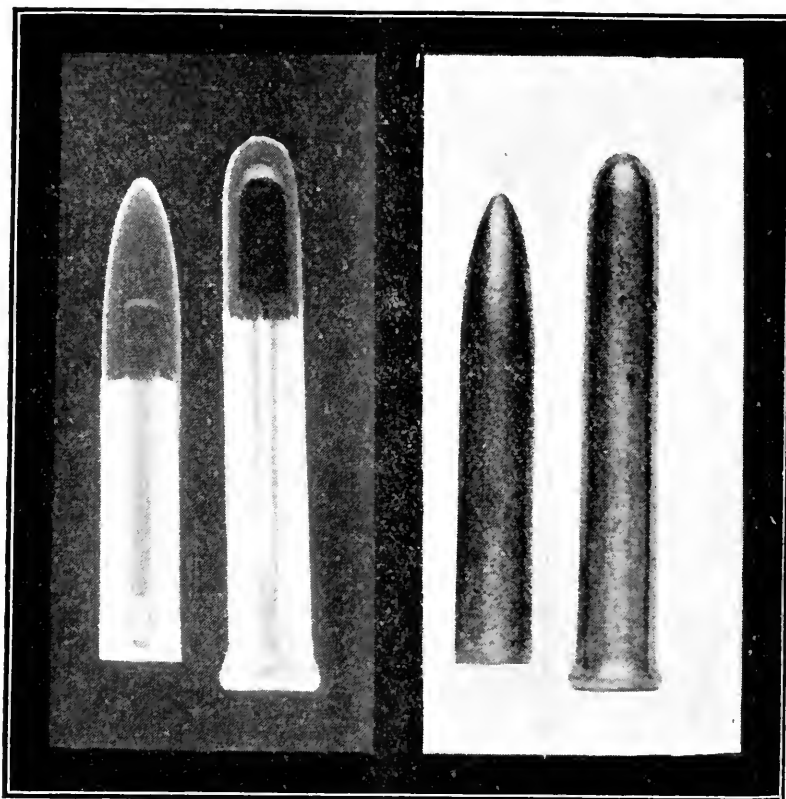


FIG. 3.

German explosive cartridges. Right, radiograph; left, photograph.

DISCUSSION.

The CHAIRMAN, in opening the discussion, said he was glad the Arsenal was developing so useful an instrument for inspection purposes. Some seven years ago he had found in an aeroplane works not very far outside Paris a complete radiographic equipment, and had looked over it with interest, but the report he had got from this purchaser was that it was very dangerous and liable to give a malignant disease to those who used it; he himself was only allowed to peer into the room. No progress could be made by a firm using the apparatus without understanding. In Dr. Pullin's Paper we could see how precautions against the risks had been taken so as not to obviate the free use of X-rays for examination and testing.

Group-Captain E. F. BRIGGS said that any means which could be relied upon to show up cracks and faults in aeroplane parts was of great importance. Metal propellers were now being constructed, and a certain number had been in the air recently, and efforts were being made, by employing metal in lieu of wood, to

* It has been found impossible to reproduce many of these slides.—EDITOR.

overcome the effects of heat in the East. In this connection a large amount of welding was employed, and as far as he could see, examination by means of X-rays would be most useful if it could be carried out in general practice. He was doubtful as to whether, at the present time, it would be practicable to put down a plant at each works, or whether it would be possible for the Aeronautical Inspection Department to transport plants in order to make special examinations. As regards other parts of metal aircraft, such as spars and ribs, at the present time one did not resort to welding, these were nearly all rivetted, and he doubted

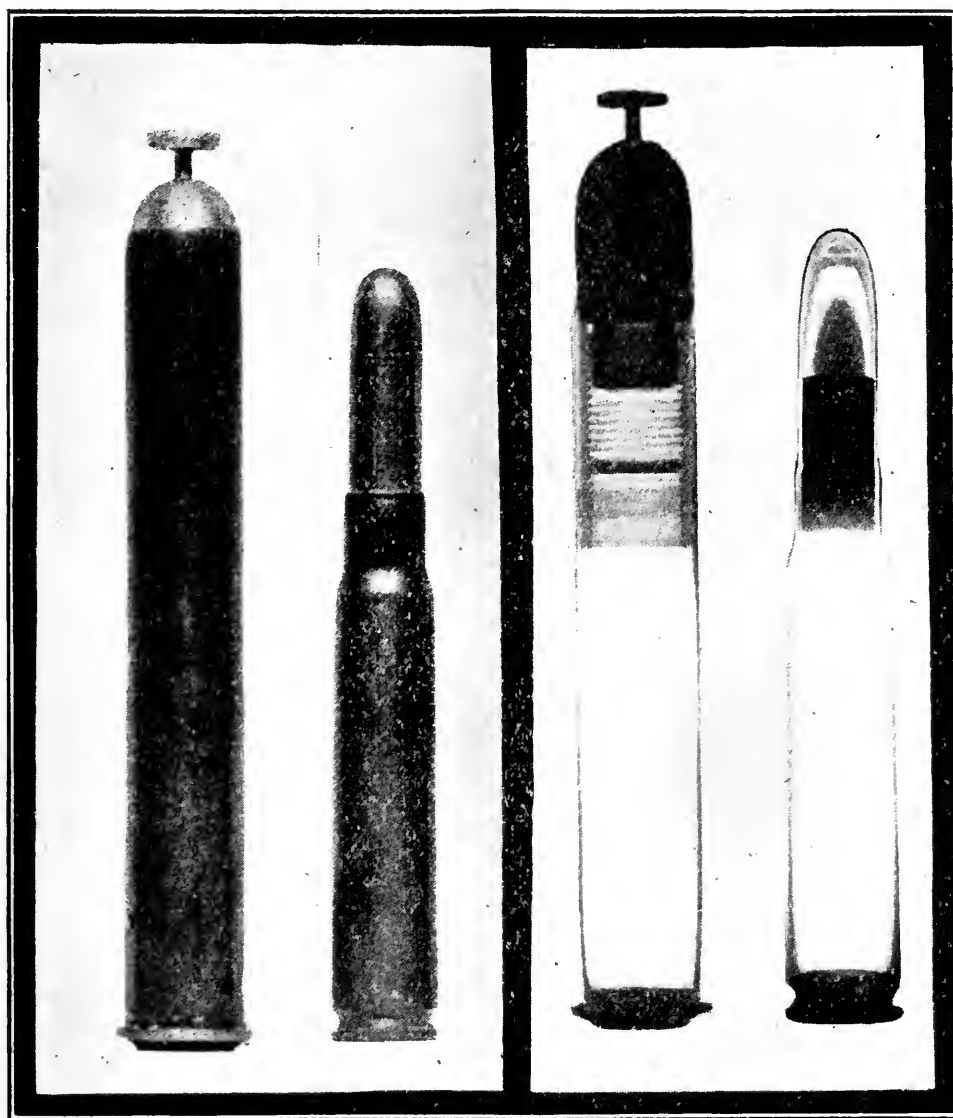


FIG. 4.

German explosive ammunition. Left, photograph; right, radiograph.

very much whether radiological inspection would do much good in that connection. He asked the Lecturer what would be the cost of installing plants which would deal with such items as propellers, because that at the moment seemed to be rather a governing factor.

Mr. W. O. MANNING agreed that such an apparatus would be of considerable use in connection with the examination of welds. With regard to many of the specimens shown on the screen, the trouble could have been found out by ordinary visual inspection, and he was of opinion, therefore, that for ordinary purposes the system was rather too complicated. There would appear to be some difficulty

in the interpretation of results when they were obtained, if the radiograph showed a curious marking it did not seem obvious what it was. It might be a flaw, or some slight trouble which was not detrimental in a particular part, or it might be an exceedingly serious matter. Again, he understood that if a crack were

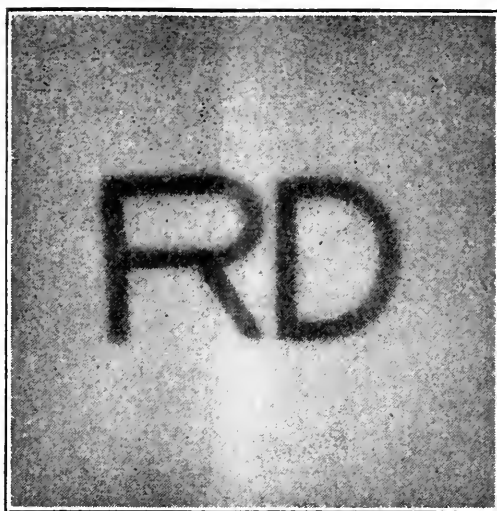


FIG. 5.
*Lead letters R.D. radiographed
through 3 inches of steel.*

edge-ways on the apparatus, it could be seen quite clearly, but if it were the other way round it was possible that it would not show up at all. It might therefore be necessary to examine all specimens on all three planes. He considered the difficulty of interpretation as very serious. It must depend to a large extent on the judgment and experience of the operator. This experience could only be obtained by com-

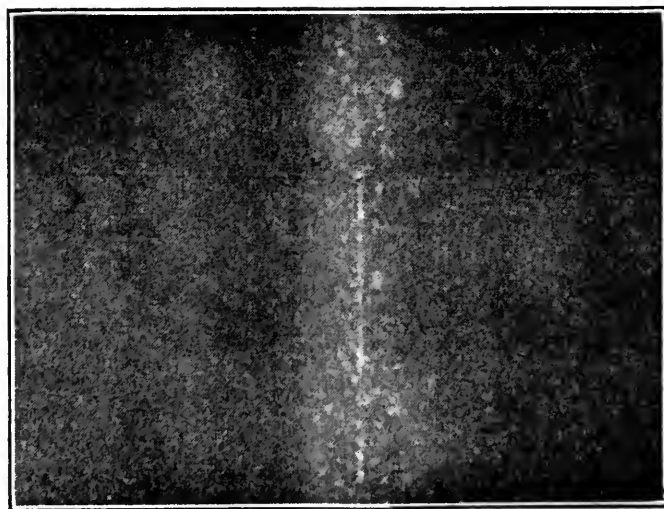


FIG. 6.
Weld in steel plate $\frac{1}{2}$ inch thick.

paring the appearance shown in the radiograph with the actual fault discovered after the specimen has been cut up. Before the process can be used a supply of trained operators must be available, and it does not appear that they exist.

Major CARTER asked the lecturer whether it was usual when examining a specimen to turn it at right-angles, in order to get an inspection in two dimensions, and whether any work had been done by Dr. Pullin on aircraft engine parts, such as crank cases or welded cylinder heads.

Dr. G. W. C. KAYE (National Physical Laboratory) expressed his appreciation of the work carried out at Woolwich. Some of the photographs which had been shown were very beautiful, especially those dealing with munitions of war. As regards aircraft, the first work on this was done during the war by the Aeronautical Inspection Department in association with Dr. Knox. Some of the results were published before the Faraday Society in 1919. The Air Ministry had an outfit installed at the N.P.L. at present, and a certain amount of work had been done there. One of the reasons why radiology had not made such progress in engineering as it might have done was the present state of development of both apparatus and technique. We were, as regards X-rays, in a sort of "farthing dip" era, and we had a long way to go before X-rays could be popularised in the commercial world. The apparatus had got to be far more powerful, and the X-ray bulb improved out of recognition. There was in fact a great deal of work to be done, and progress could only be made through continuous research. He warned his hearers, however, that results must not be expected too soon, investigators must be given a chance.

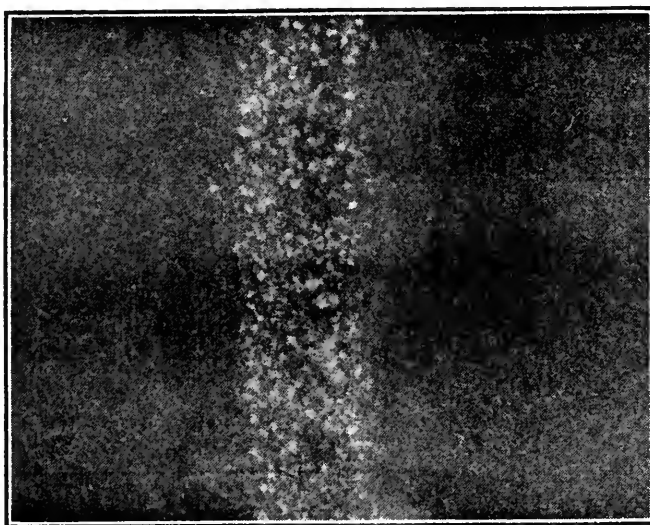


FIG. 7.
Weld in steel plate 1 inch thick.

Colonel C. R. B. OWEN (War Office) said that the photographs of fuses, detonators and things of that sort were very suggestive to anybody interested in small arms ammunition. Whether radiology in this connection would be really applicable it was beyond him to say, but during the war there were many things in connection with which the apparatus would have been a help had they been able to apply it suitably, such as the presence of two bullets in a cartridge case, and the omission of the powder charge, troubles which in many cases were believed to be due to deliberate action. During the war cases even occurred of foreign substances being inserted into the cartridge in place of the charge, which made detection of a faulty cartridge by weighing very difficult. An apparatus of the nature under discussion might, in certain circumstances, be useful in detecting such faults, but from the practical point of view the great amount of ammunition that has to be handled in a large war would preclude its general use. Should it be possible however to produce a plant for say £20 such an apparatus might have a value in special cases.

Dr. PULLIN said he thought so. Where inspection was to be economical, it might be possible in some cases to modify a specification. For instance, in the case of the filling of a small arms cartridge, the inclusion of a very small percentage of opaque salt, barium salt, would pay from an inspection point of

view, because that would enable large numbers to be passed through a screen at once. It need only be a very small quantity, which would not interfere with the explosive property of the filling, but would render the filling opaque.

Mr. BOWDEN (Chief Superintendent, Ordnance Factories, Woolwich Arsenal) said the picture that had interested him most was that showing an insulating material. Although it had no direct bearing on aeronautical inspection, it did show how far X-rays might be of service. It was not clear from the picture how far the method was an ordinary workshop process. When one commenced mass production, one necessarily needed a means of inspection of the materials used. The picture method of inspection had proved particularly helpful during the war, and radiology was now on the way towards facilitating examination in large

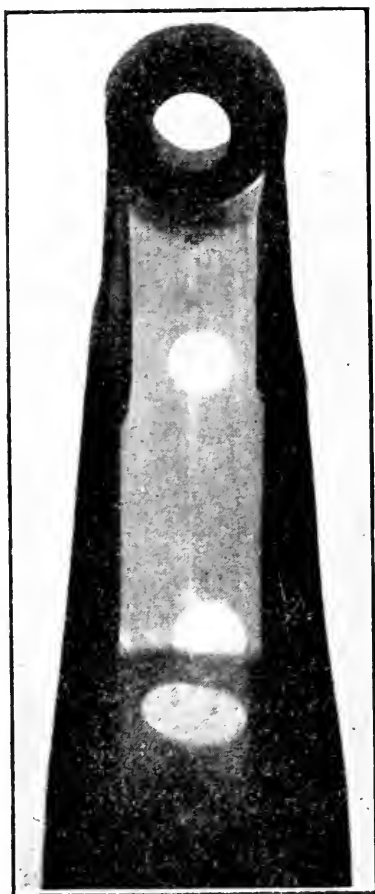


FIG. 8.
Radiograph of U-tube socket, showing faulty weld. The weld was apparently sound, but radiograph shows want of union between the parts.



FIG. 9.
Faulty weld in petrol tank union.

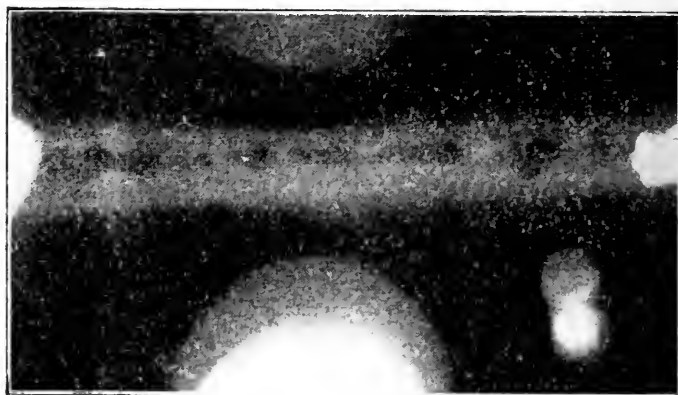


FIG. 10.
Faulty weld in interplane strut socket.

quantities. It was much quicker to pass pieces inspected over the machine than to inspect them by the manipulation of tools. There was another point, which was perhaps apart from pure inspection. The inspection referred to that evening was mainly for the purpose of safeguarding against improper functioning, against danger, and so on, but he himself could see a very wide field for radiology in the direction of saving money. If Dr. Pullin and other investigators could increase the penetration of the rays so that they would go through 6 ins. of steel, great economies could be effected in connection with the inspection of ingots, and it would be of great benefit to the manufacturer. He asked Dr. Pullin whether the voltages in relation to penetrating power were on curves which ascended in parallel,

or whether they were not like the speed of a ship, in connection with which, as the knots were increased, one had to cube the engine power, or something of that sort. He hoped radiologists were not going to lead us to that, because, if that were so, the enormous voltage which would be required to penetrate 6 ins. of steel would land us into the region of electrical pressures which we would all be afraid to go near.

Mr. CAMPBELL spoke as one of the much maligned inspectors of aircraft. At the present time inspectors had quite enough trouble to contend with without going to a contractor with an X-ray apparatus; any contractor would shoot them at sight if they appeared at his works with such a formidable weapon. There had

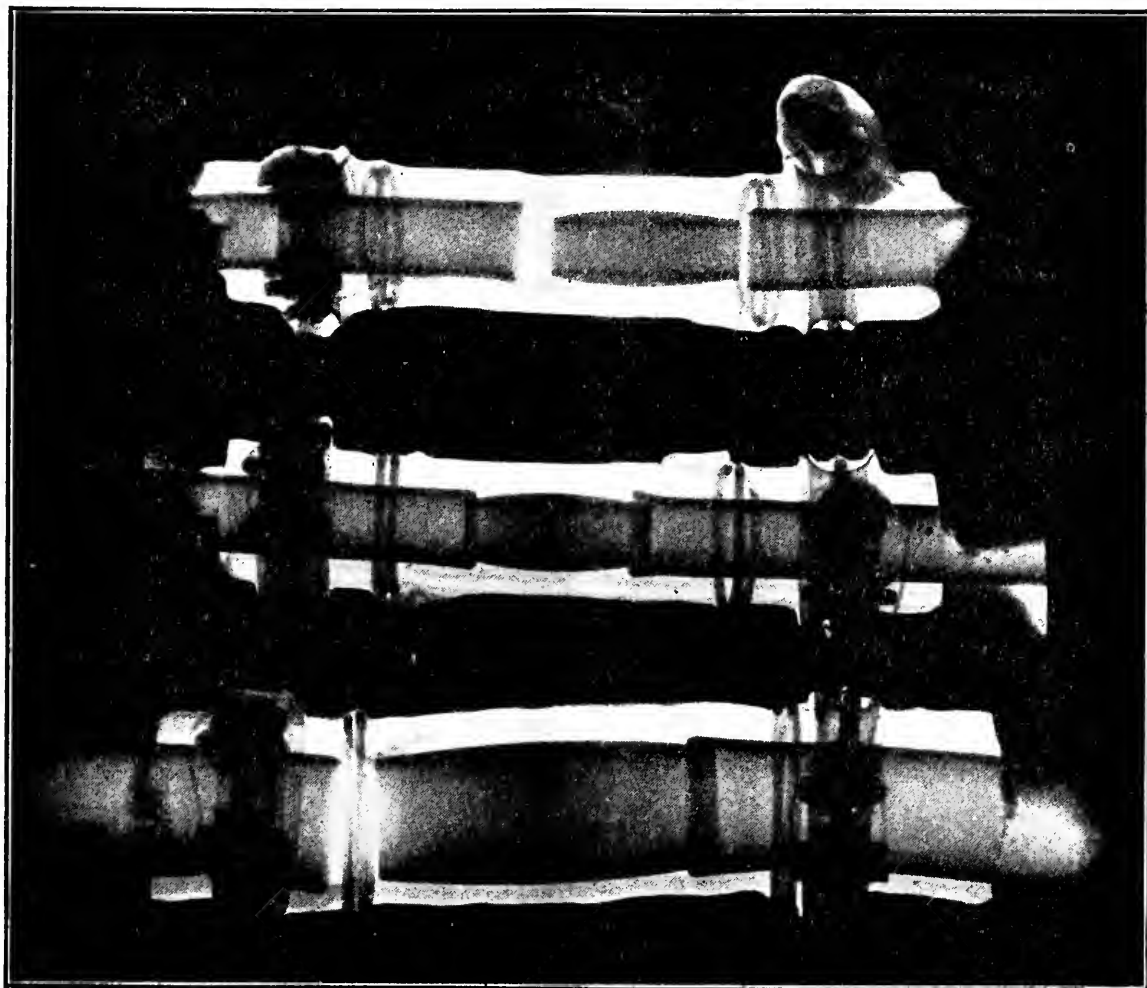


FIG. 11.

Radiographs of rubber pipe joint, showing correct and wrong positions of the internal metal sleeve.

been one or two examples of faults in timber shown on the screen, and there was one showing a case of particularly pronounced cross grain. If he had an inspector who could not immediately spot cross grain, or what was more difficult to spot in timber, namely, spiral grain, he would fire him at once. He agreed with the second speaker that there were in addition quite a number of the examples shown in which the faults could be seen quite easily by a straightforward examination. Unfortunately, there were times when these faults were not to be seen so readily. The main faults they had to contend with were fakes; a workman made a mistake, and purposely faked the job, in order to make it look all right, and he agreed that no ordinary human inspector could readily find a fault in such a case. If one suspected such a fault, then he contended that X-rays would be a

help, but, unfortunately, one did not know just when and where to look for a criminal fake. The control column shown on the slide was a case in point. As the end of the socket was open, a man, provided he examined the control column as such, could see whether the tube was bedded down or not, but if the control column were fixed in position on a machine it would be difficult for him to see such a fault. In the bedding of timber struts into sockets, if the struts were carefully fitted, the chances were that external examination would give some idea of whether they were bedded down or not. At one time they advocated inspection holes at the bottom of all sockets in order to see whether struts were adequately bedded down, but he was of the opinion that inspection holes tended to induce a workman to fake a job so as to look all right.

Group Captain Briggs had mentioned metal propellers, and he himself had had a little to do with their development on the manufacturing side. The problem had been, not so much the difficulty of getting a sound weld as the difficulty of getting a sound structure of the material after the heat treatment of the blade as a whole. That had been the main trouble, and he was certain that no X-ray outfit would be able to give any indication of the structure of the metal itself.

Mr. C. H. HOLBEACH (British Thompson-Houston Co., Ltd.) asked what milliamperage and what voltage the Lecturer had used in order to obtain sufficient light on a fluorescent screen to enable him to examine visually half-an-inch of steel. His reason for asking was that in all probability the use of a tube that would stand up to the powers necessary for that purpose would entail water cooling of the anode, and it should be borne in mind that the application of X-rays to industrial purposes presents a totally different problem to its use in a research laboratory. This is of particular import in considering the X-ray tube employed. The failure of the tube, whether by breakage or loss of vacuum in a laboratory, would not be a disastrous occurrence, because it is an easy matter to re-exhaust the tube with the plant which a laboratory of this nature would have at its disposal. Moreover, the exhaust pump can be permanently connected to the bulb. On the other hand, in the industrial application of every-day examination of metals the question of using the right apparatus with a high-powered tube is an important one. At the present moment no available tube would, in his opinion, stand up to the energy that would have to be passed in order to fluoroscopically examine half-an-inch of steel.

The CHAIRMAN said he did not feel as critical as some speakers had shown themselves to be as to the prospects of radiography in engineering, because, although many had alluded to the fact that the radiographic apparatus would help the inspector, some speakers had forgotten that the manufacturer would take care to have a radiographic apparatus of his own, and even if some wily person used barium paint to darken light places, progress would result from the introduction of the apparatus and its use. He felt that in the long run it would be a very valuable instrument indeed. As regards defective welds, if the radiograph would really disclose what were sound welds, welding might yet be allowed back into aeronautics with advantage to everyone. The radiograms of defective welds shown that evening had indicated quasi-mechanical defects such as butt joints that were not butt-jointed, but they did not, he thought, indicate the other trouble which had been found in welding. The heating of the metal close to say, one millimetre from the weld to a certain temperature, was not infrequently found to reduce locally a tensile strength of 25 tons down to a tensile strength of about 10 tons over a narrow belt. Therefore, the strength of the piece was so greatly reduced that it ought not to occupy a position of stress. If the radiograph could distinguish between steel at 10 and at 25 tons tensile strength it would be a priceless instrument, but he doubted whether it could be brought to do so. On the whole, the bringing of X-rays into use was a thing which aeronautical engineers should welcome. They were always dealing with the ultimate limit of strength, and cutting away to the finest possible degree, and there seemed no doubt that, since so

much depended on a mistake, which might be either viciously or accidentally made, any really far-reaching weapon which looked into unseeable places would be of immense advantage.

Dr. Pullin had asked that he might be allowed to reply to the discussion in writing, because he had an appointment to keep. In conclusion, the Chairman moved a hearty vote of thanks to Dr. Pullin for his interesting and suggestive Paper.

REPLIES TO CRITICISMS.

In reply to Group Captain E. F. Briggs, certainly one of the most generally valuable applications of X-rays was to be found in the examination of welds from the point of view of general soundness of the weld and also the development of blow holes and cracks. It would be of advantage if I could be furnished with specimens of the propeller welds mentioned by Captain Briggs, I could then more accurately suggest the figure involved in the design and construction of a suitable installation. It might prove of great advantage if a general X-ray outfit were installed in every aeroplane factory which could be adapted by means of specially designed viewing screens and suitable controls to serve many purposes, not necessarily for routine work only, but which could be used in all special and doubtful cases. Such a set would call for very careful and economical design, and should not cost more than £200. I should be very happy to consider such a set, and go more carefully into its general use. With regard to rivetting, X-rays can certainly be of use here, not only with regard to examining unseen parts for, say, the presence and proper functioning of rivets, but with suitable technique the fit of rivets can be examined.

In reply to Mr. W. O. Manning, the object of the lecture was perhaps slightly misunderstood by Mr. Manning. The question as to whether the objects shown on the screen were detectable by visual examination does not matter in the least; the idea of the pictures was to show how defects were shown by X-rays. I want members of the audience to submit specimens, of which there must be a large number which defy visual examination. This surely is possible, judging by the number of cases where visual examination has actually failed, sometimes with disastrous results. I want to make it quite clear that the specimens shown were not selected necessarily as definite suggestions for actual examination, but to illustrate the sort of result that could be achieved by X-rays. With regard to the interpretation of the radiographs a man could very easily be taught what the various shadows mean. Radiographs are nothing more or less than shadows pictures, and the shadows merely indicate differences in density.

In reply to Major Carter, I am not aware of any work having been done on the radiographic examination of welded cylinder heads or crank cases. It might be of interest to point out here that, at the present stage of development, hair cracks in steel are not possible of detection by X-rays. In the work at Woolwich specimens were always examined twice, one examination being from a point at right-angles to the other where practicable.

In reply to Dr. Kaye, I quite agree with Dr. Kaye that X-ray research has a long way to go before it achieves all that we who do research work on the subject believe it is capable of achieving in the commercial world. I am also grateful to Dr. Kaye for emphasising the fact that results must not be expected too soon. Radiology is an expensive and laborious work and the workers are very few, but the progress that has been made and the enormous importance of the subject, demand that every facility should be given to help work that will certainly ultimately result in great economies, and what is more important from the point of view of aircraft, very greatly increased safety.

In reply to Mr. Bowden, the examination of electrical insulating material by X-rays is of the greatest possible value and certainly could very easily be made

an ordinary workshop process. The application of radiological examination to mass production is often merely a matter of careful design of special X-ray apparatus to deal with the particular article to be examined. In suitable cases such inspection can be very rapidly carried out. As an example of this I might mention that such an inspection of many thousands of a certain small service store has been carried out at Woolwich at the rate of 2,000 a day and at a merely trifling cost for materials. This work was done on the ordinary research installation. With specially designed apparatus and proper organisation for handling large quantities, this total could be considerably increased. No other means exists of ascertaining the internal condition and consequent safety of this particular store and had radiological methods not been available it would have been necessary to destroy the whole supply. The examination of large thicknesses of metal certainly requires the use of higher voltages, but the situation is not so alarming as suggested by Mr. Bowden. It must be remembered that from the practical point of view, a great deal is to be obtained by increasing the current carrying capacity of our X-ray tubes, and work in this direction is in progress.

In reply to Mr. Campbell, my remarks in reply to Mr. Manning would apply generally here. I would merely add that as research progresses X-rays will become more and more useful as a means of accurately examining materials and the manufacturer will have to realise that a very formidable instrument is becoming available for examination purposes. At the present time perhaps it is neither economical nor desirable to employ X-rays as a routine method of inspection, but undoubtedly an installation in an aircraft factory for isolated reference would even now prove very valuable always provided that the installation were properly designed and sufficiently adaptable. Any method which will enable an inspector to "see" inside a specimen and examine it under conditions that inhibit ordinary visual inspection is obviously a thing of high potential value. It remains to develop the method until it becomes indispensable. At present suggestions are urgently wanted to assist that development. Negative criticism has hardly the constructive value that is so essential to progress.

In reply to Mr. Holbeach, 10 milliamperes and the voltage corresponding to an alternative point spark gap of 10 ins. operated under suitable conditions. The source of current was an oil-immersed closed core transformer. The experiments referred to were all carried out in a research laboratory.

In reply to the Chairman, I should in the first place like to thank him for his very illuminating and helpful remarks. The object of the lecture, as I have said before, was to elicit from an audience of specialists the directions in which the development of X-rays would have a maximum value. I would like to remark in the first place that there is no difficulty at present in designing an X-ray set that shall be perfectly safe. With regard to welding, X-rays do afford at present, within certain limits, the only really satisfactory method of examining welds as such. Concerning the changes in the metal which are produced by the heating necessary in welding, I do not think that simple radiographic examination will ever be of much value, but various research workers are at present tackling the problem by means of X-rays in another manner. I refer, of course, to X-ray crystal analysis on the lines of the methods introduced by Debye and the Braggs. It is early yet to speak of particular progress, but the results are, on the whole, very encouraging, and certainly inspire the hope that radiology will afford valuable aid to the metallurgist, especially perhaps with regard to information about changes in metals due to heat treatment.



SOME TECHNICAL ASPECTS OF AVIATION IN CANADA.

BY E. W. STEDMAN, FELLOW.

INTRODUCTION.

Before dealing fully with the technical side of aviation in Canada it is advisable to discuss the different kinds of work that can be carried out by aircraft in this country. A few of these duties are described below.

Forest Insect Investigation.

In forest areas it is sometimes found that insects are attacking and destroying the timber, but it is generally difficult to determine the extent to which the insects have attacked the timber and the direction in which the pest is advancing. It has been shown that by flying over the forest area affected a trained forestry observer can decide at once where the insect pests have been at work and the direction in which the trouble is proceeding, so that he can form an opinion as to where any protection measures should be applied.

Recent experiments in the United States have shown that in some cases the pests can be dealt with by poison distributed from an aeroplane.

Forest Reconnaissance, Forestry Photography and Forestry Survey.

In any new country the extent, size and nature of the timber can be quickly determined, photographed and sketched on existing charts or maps by forestry



FIG. 1.

Photograph illustrating forestry reconnaissance from the air.

observers working from an aeroplane, and similarly the organisation and conduction of logging operations can best be directed by an observer who has viewed the whole situation from the air.

Fire Detection and Transportation of Fire Fighters.

It is recognised by everybody that is interested in the subject that the prevention or early suppression of forest fires is a subject that requires a tremendous amount of attention and care. With the usual methods of forest patrol, in which the observers make use of existing water-ways, it is not always possible to observe a forest fire in its initial stages as the fire may occur in districts not easily observed from a water-way; also the district under observa-

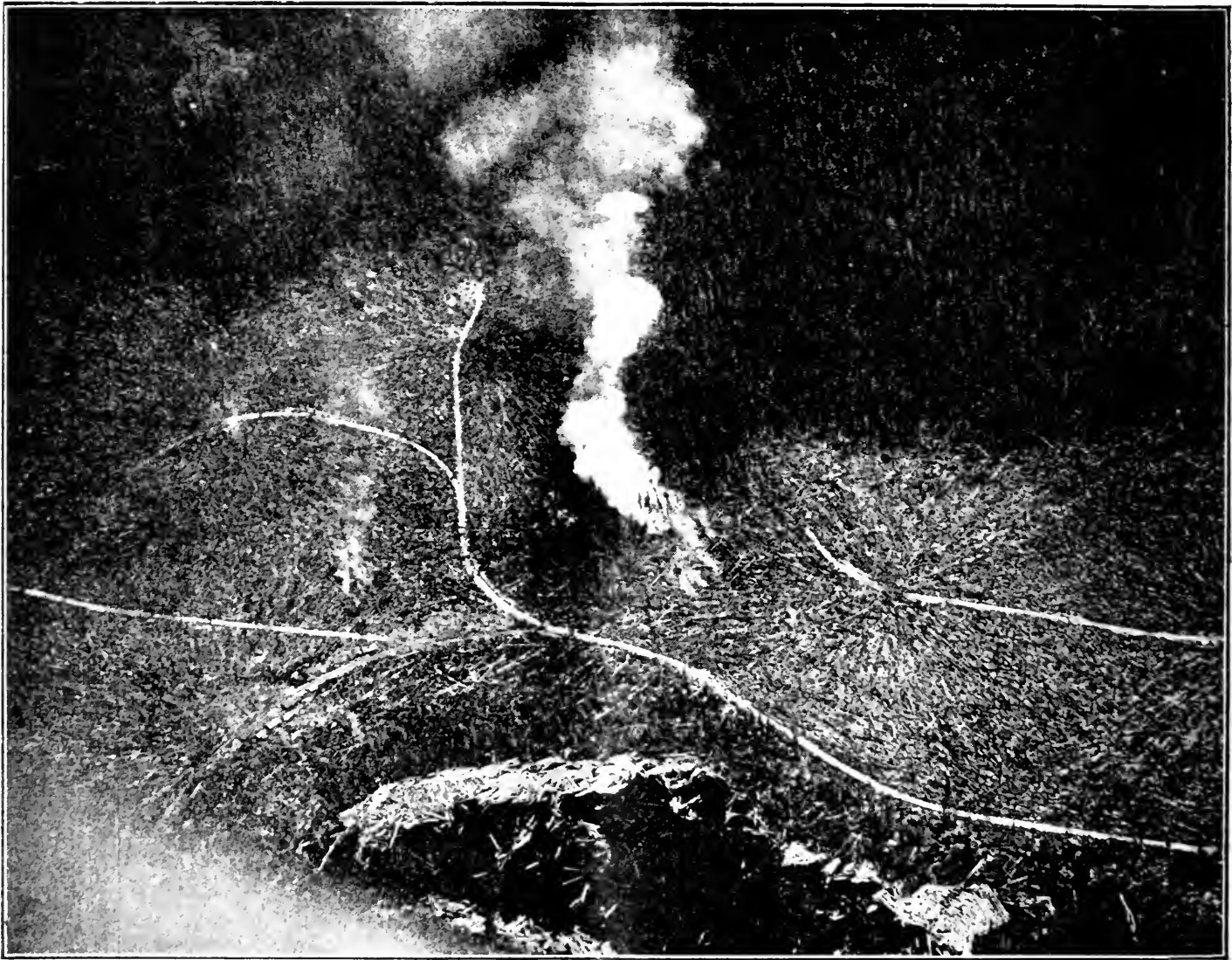


FIG. 2.

Photograph illustrating detecting fire from the air.

tion by an observer at any one time is small. Similarly, the observation posts erected for forest protection will usually have a fairly limited outlook, but by carrying out forest patrols from the air it is possible for the observer to have an enormous tract of country under observation at any one time, and further, the smallest indication of smoke is noticed immediately, with the result that it is more frequently possible to conduct fire-fighting operations before a fire has attained any size. The moral effect of an air patrol on settlers or campers is in itself a large contribution towards the elimination of forest fires.

If a forestry observer patrolling by canoe finds a large fire, it is usually necessary for him to return to some base in order to obtain the necessary help. This double journey occupies a large amount of time, during which the fire may have increased considerably in magnitude.

In forestry patrol from the air the procedure is different. If the fire is small, the seaplane is landed at the nearest lake or water-way and the crew proceed to the scene of the fire. If they are unable to cope with the fire themselves, they leave one or more men and return at once to the base for assistance. The seaplane returns with extra men, food, etc., and keeps up

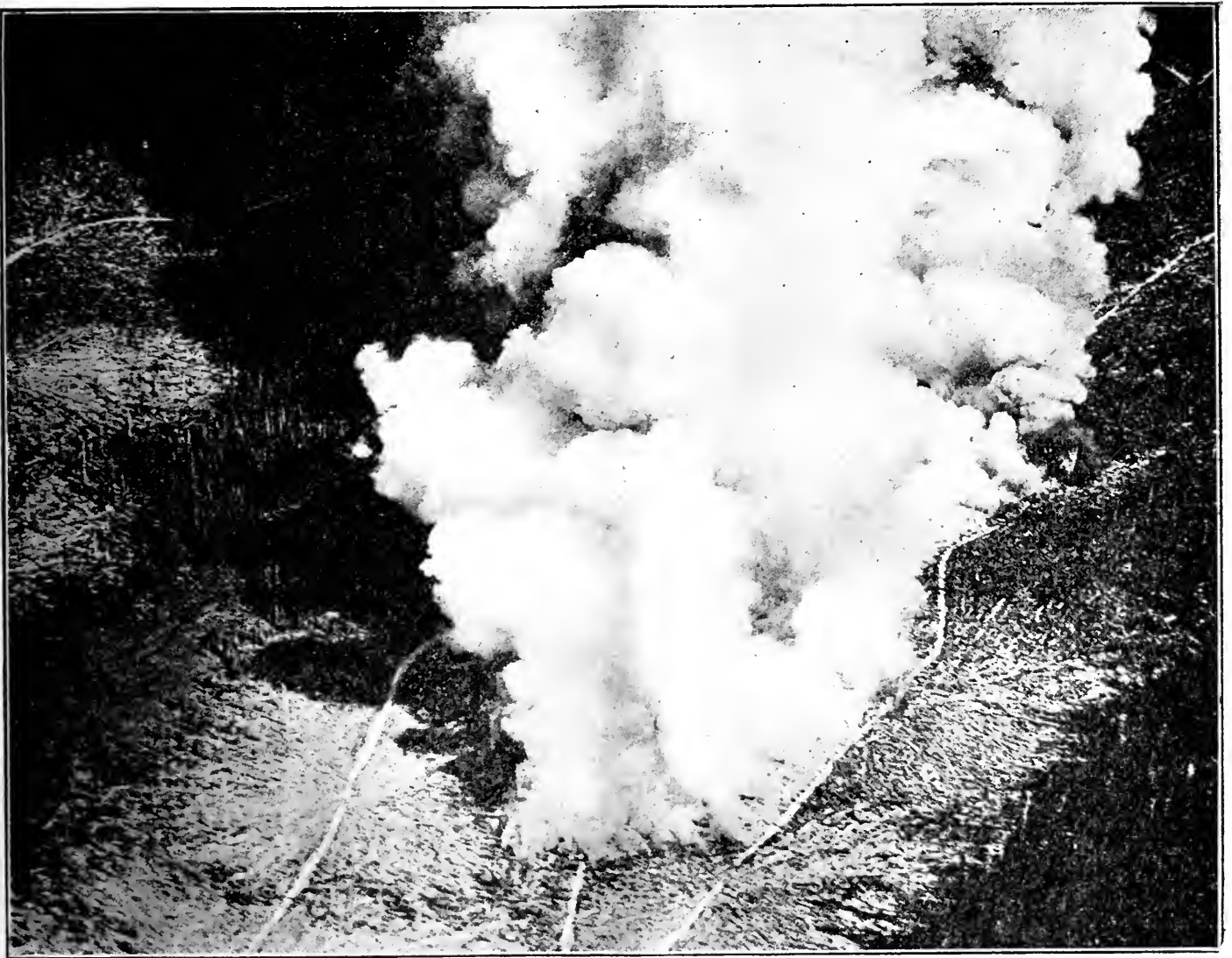


FIG. 3.

Photograph illustrating detecting fire from the air.

communication with the base as long as the fire fighting is in progress. As soon as the fire is under control the fire-fighting crew is carried back to the base and is ready at once for any other emergency, or they may be transported direct to another district.

Water Power Reconnaissance.

In deciding upon a water-power scheme it is often necessary to obtain particulars of some part of the country that is not well mapped in order to determine the watershed area and details of the direction of flow of water. For this purpose there is no method which is more convenient than the air for

obtaining the information required, as a comprehensive grasp of the whole situation can be obtained in the course of a few short flights.

Survey Reconnaissance and Transportation of Surveying Parties.

In carrying out primary triangulation of mountainous country it has been necessary in the past for the survey parties to lay out roughly the figure desired and then to select mountain peaks which might prove suitable for stations. Having selected these peaks it is necessary to climb to the top of each of the peaks in order to see that the range of vision is such as is required for a station,

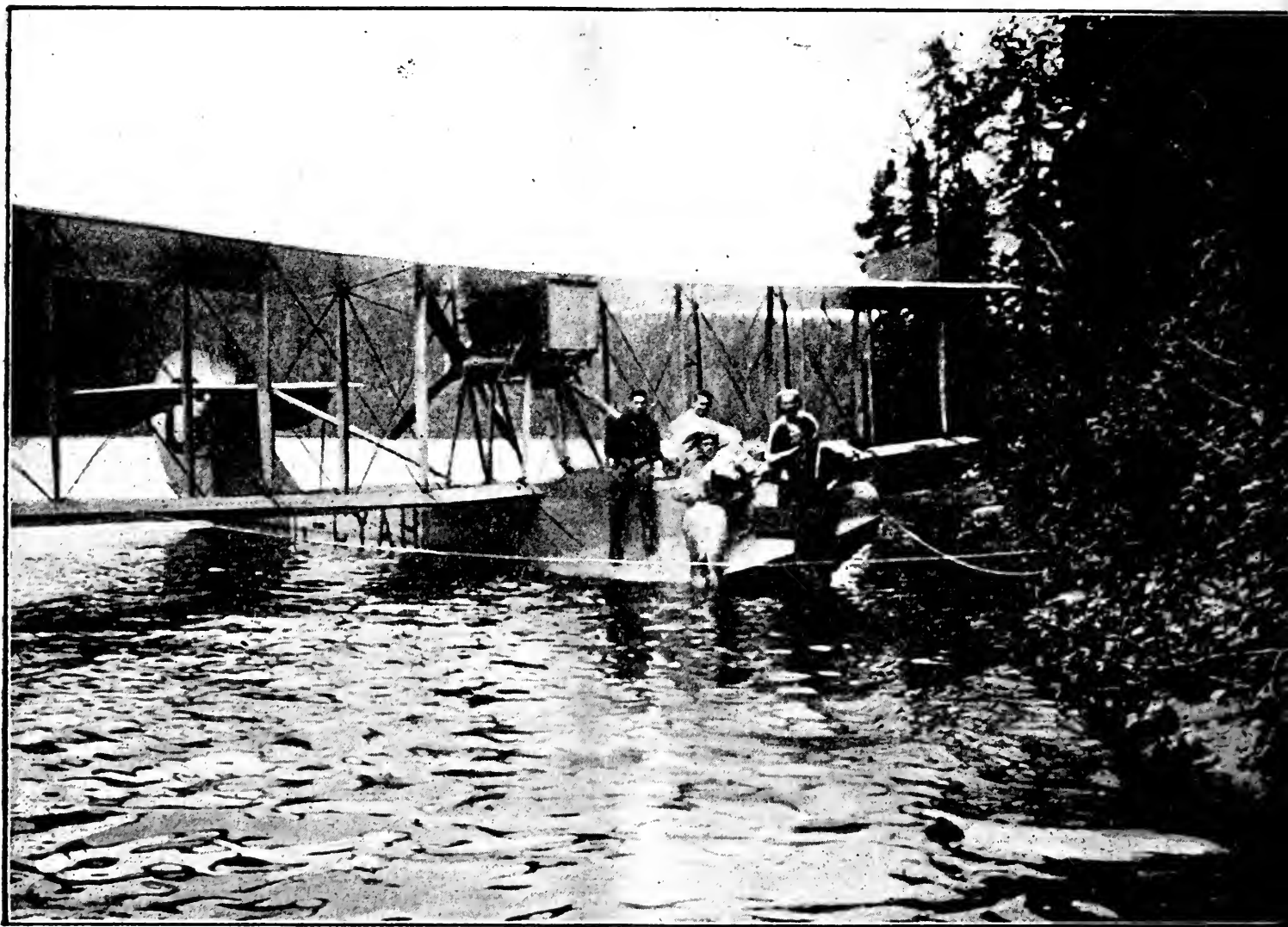


FIG. 4.

Transportation of fire fighters.

and if not, a different peak has to be selected and climbed before the position of the station can be decided upon. Under the conditions used in the past it has always been a matter of doubt as to whether the figure obtained was the best possible in the country or whether something better could not have been found by spending more time in selecting the stations. The whole procedure can be proved and expedited by the use of aircraft, as it is possible for the man in charge of the surveying party to be carried over and around all the peaks in the neighbourhood of which he wishes to place a station so that he can obtain at once an idea as to which of the peaks is suitable for the station and so save an enormous amount of time that would otherwise have been wasted in climbing difficult and dangerous peaks. Also he can select a better figure

for his triangulation, as he is able to inspect a much larger number of peaks. Having decided on the position of his stations the aircraft becomes of primary importance for carrying the parties to their respective stations and keeping up communication between the parties and their base by carrying in supplies, etc., thus saving a large amount of time that would otherwise be wasted in packing and transportation.



FIG. 5.

Photograph illustrating survey reconnaissance.



FIG. 6.

Photograph illustrating survey reconnaissance.

Geological Reconnaissance.

In opening up new country it is necessary to send out geological parties, who prepare geological maps of any particular part of the country. This process occupies a large amount of time as there may be very large tracts of a geological formation that is of little interest but which the party have to traverse. It is well known that geologists can roughly divide up the country into different formations by obtaining a bird's eye view of the nature of the country. If the geological reconnaissance party is carried by air they can be rapidly transported over country on which there is no change of formation and landed at any point at which there appears to be a change in the geological formation or other matter



FIG. 7.
Transport of survey parties.

of interest. In this way preliminary geological surveys can be very rapidly accomplished.

Waterway Photography, Waterway Reconnaissance, Harbour Board Photography.

A large number of rivers have in them sand-bars which are continually changing their shape and position so that in such a river navigation is always liable to obstruction due to change in the position of a sand-bar. Aerial photographs have shown that sand-bars in a river can be very accurately mapped from the air, and in connection with water-ways of this type a considerable amount of worry and expense could be eliminated if photographs of all the sand-bars or other obstructions were taken periodically and issued in a form that would be of assistance to navigators.

In connection with harbours, similar work could be carried out.

Photographic Survey of Cities.

From time to time several mosaics of cities have been made, and these have shown the importance of different branches of aerial photography from the point of view of the town planner.

Customs Patrols; Reclamation Reconnaissance; Fishery Protection; Scenic Photography; Cinematograph Photography; Passenger Carrying between Cities; Passenger Carrying Joy Riding; Photography of Factory Plants; Exhibition Flying; and Naval and Military Flying need no comment except that for service purposes the necessity for flying all the year round is emphasised, and last but by no means the least, *mail carrying and express freight carrying*, which also requires a year round service.

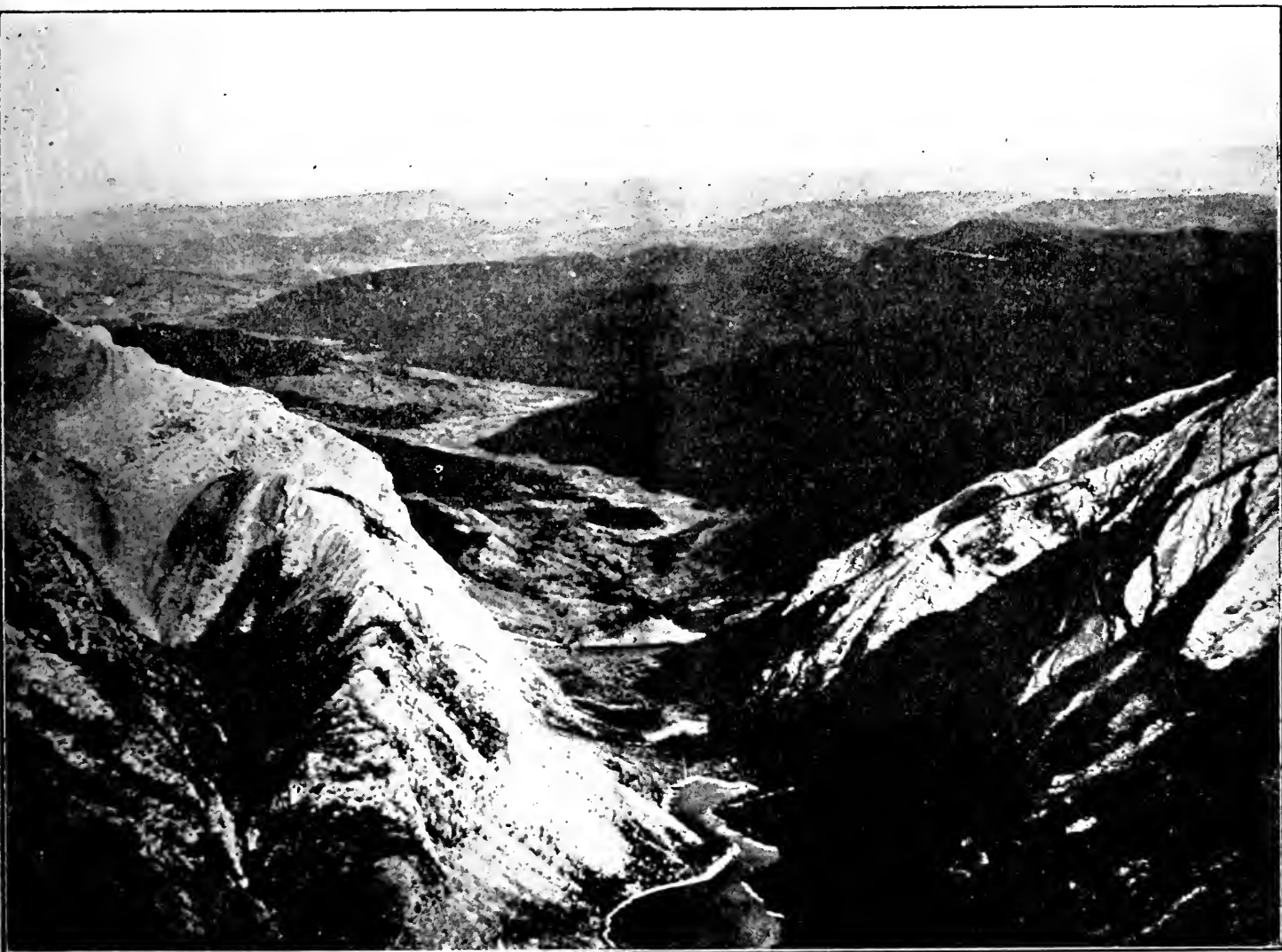


FIG. 8.

Photograph illustrating geological reconnaissance.

COUNTRY TO BE TRAVERSED.

In so far as aviation is concerned, Canada can be divided into two districts :

- (1) The prairie country, extending from the foothills of the Rocky Mountains east as far as Winnipeg, north as far as Edmonton, and south to the international border.
- (2) The remainder of Canada.

The first district consists of rolling plains, on which land machines can find landing grounds with very little difficulty.

The remainder of Canada is largely filled with lakes, with the result that a seaplane or flying boat is the most suitable type of machine for summer use.

The extent to which the lakes intersect the country cannot be realised until large-scale maps have been examined in detail, or better still, the country has been flown over. Under these conditions it is at once realised that in almost every district lakes suitable for landing on are available, but in the more mountainous districts a good performance machine is necessary in order that the high land can be negotiated after the water has been left. Enormous tracts of land

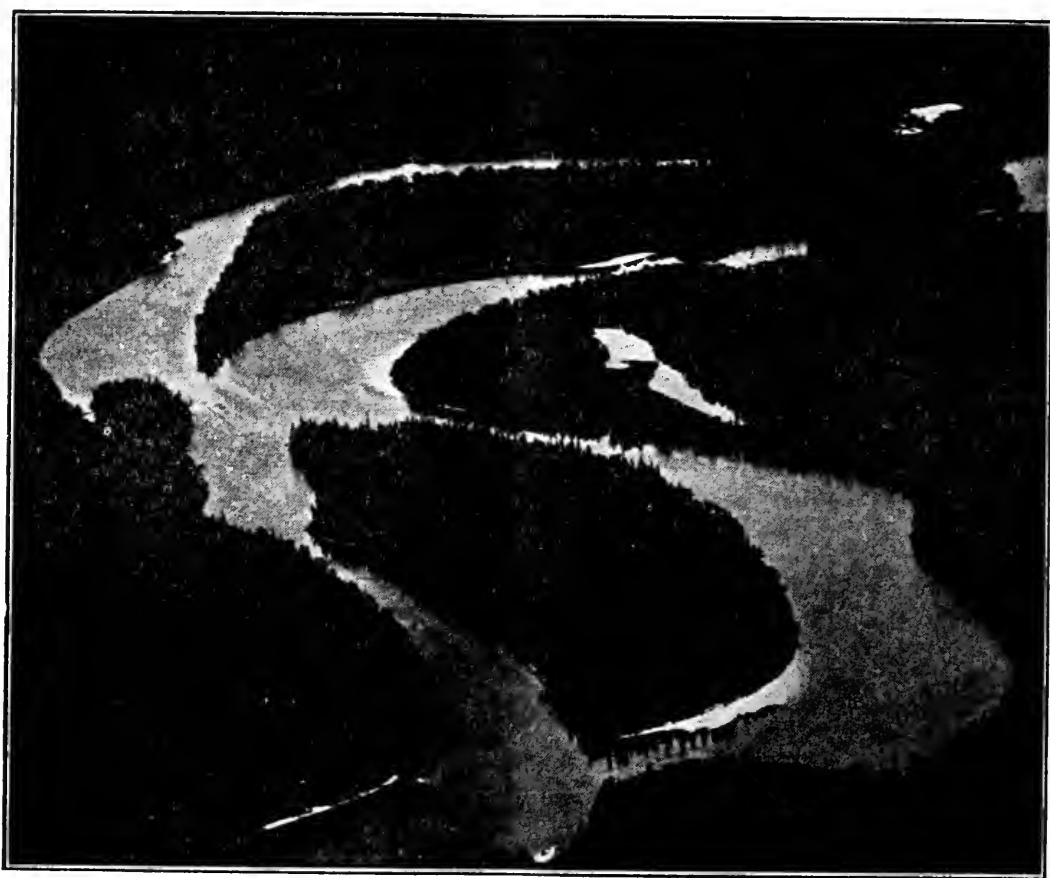


FIG. 9.

Photograph illustrating waterway survey.

to the north of the railroads can be patrolled, surveyed, or otherwise developed by the use of seaplanes during the months that the waters are open to navigation.

The question of flying in these districts during the winter months is one worthy of the serious attention of aeronautical engineers, as the conditions which occur in the north part of Canada with its enormous undeveloped natural resources are the same as occur through very large tracts of country in Asia and Russia, which are also known to possess large undeveloped natural resources, and which the advance of civilisation will demand to be developed.

It is only necessary to realise the area of timber and mineral-producing country of the Ungava, which forms the larger part of the Quebec Province, and the wealth of the McKenzie River Valley to see the importance of developing rapid transportation for exploration, prospecting and surveying parties, etc.

During the summer months the problem is simply one of organisation, financing, etc., the engineering part being the same as would occur on any other seaplane route in a temperate climate; but so much more could be done if transportation could be carried out the year round, and with this object in view any research work that has been carried out in Canada has been mainly directed to the solution of problems connected with winter flying.



FIG. 10.

Photograph illustrating harbour survey.

Canada is the only portion of the British Empire in which the problem of winter flying can be systematically studied, but the results so obtained would be of value to the rest of the Empire.

TYPE OF MACHINE.

For summer flying, in a large part of Canada a flying boat will meet most

requirements. It has been found that for forest patrol and reconnaissance it is desirable to carry about five people made up as follows:—

One pilot.

One photographer.

Two forestry observers, who sketch and make notes of the country passed over (one from each side of the machine); and

One mechanic.

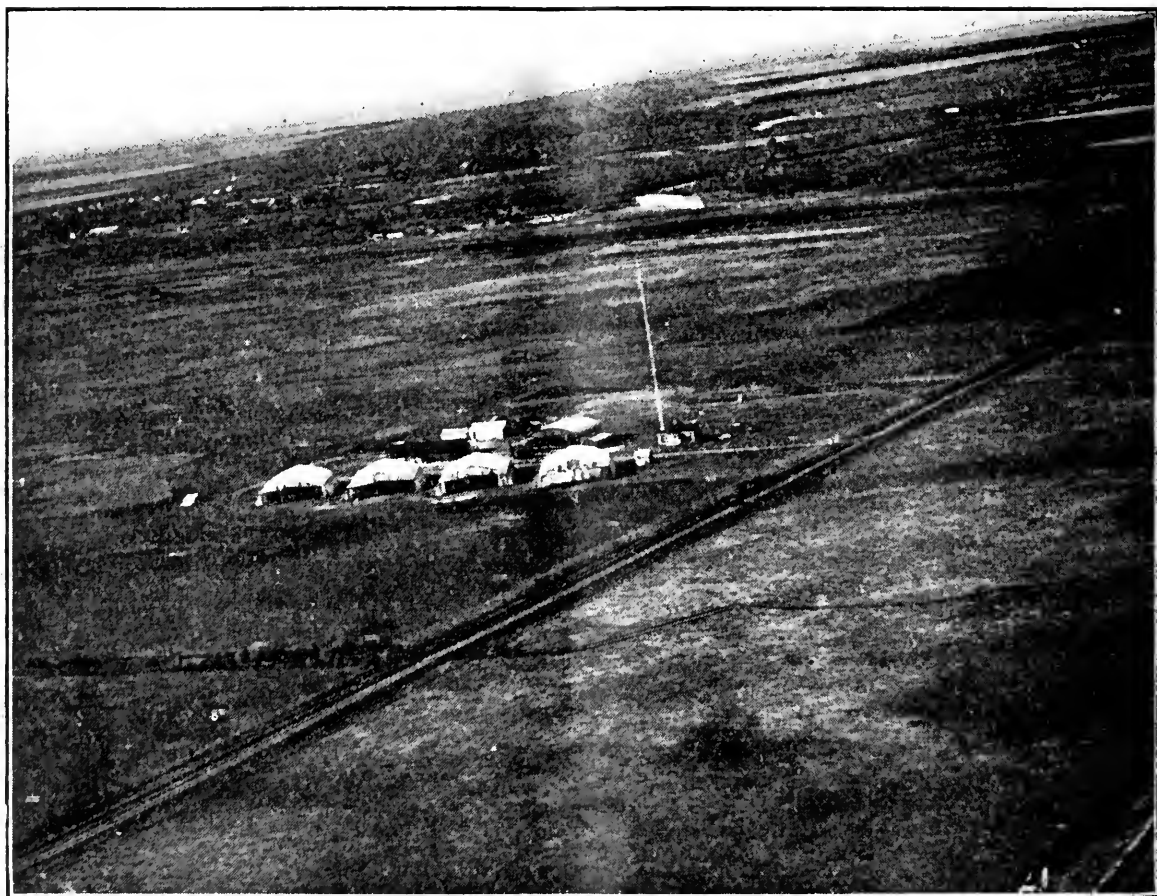


FIG. 11.

Aerodrome in prairie country.

It is also desirable that the machine should have capacity for fuel for six hours' cruising, although this may not necessarily be carried with a full load of passengers and their gear. One essential point to remember is that when quite light, that is, with just a small amount of fuel and pilot only, the machine must be capable of getting off from a small lake situated at a high altitude and must possess rapid climb under these conditions. This quality is essential to take care of the case when a machine is forced to land in a small and badly situated lake, so that by lightening the machine the pilot can get it out of the lake and land in some more suitable spot later. A machine of this type is useless during six months in the year, when the lakes and rivers are closed to navigation, and one question to be decided is whether it is possible to fit some sort of ski landing gear on the lines of an amphibian landing gear that would make a flying boat suitable for use in the winter.

In the prairie country, the work up to the present has consisted mainly of forestry patrol along the eastern slopes of the Rocky Mountains. In this district, aeroplanes have been used, and owing to the fact that landing grounds are situated at a high altitude and that the flying conditions are very abnormal, due to the great height of the peaks that have to be negotiated and the varying wind currents, it has been found desirable to use a single-seater scout of rather special type. This single-seater machine must have a very low landing speed, as it is desirable that the machines should work from aerodromes situated in the foothills close to the district to be patrolled. In these districts the aerodromes would necessarily be very small and situated at a great altitude above sea level, which condition would necessitate a low landing speed for the machines, a requirement which is further called for by the fact that any forced landing would be on the side of a heavily timbered mountain or in a lake.



FIG. 12.
Typical lake country.

Another requirement for this machine is high rate of climb. This is called for, not only for clearing obstacles immediately after leaving the aerodrome, but also to meet the case where a machine may be trying to fly out of a valley but actually be climbing in a rapidly descending air current, with the result that unless the machine has a good performance it may actually lose instead of gaining height. The question of top speed is of very small importance, as for forest patrol work it is not necessary to have enormous speeds such as would be called for with a fighting scout. The only condition requiring high speed is that the machine must be able to negotiate any adverse winds likely to be experienced. From the above description it is seen that a modern fighting scout is quite unsuitable for this type of work.

The pilot must be provided with some means of communication with the ground, and for this purpose wireless telephony would appear to be most suitable, as it enables the pilot to communicate immediately and explain the condition of a fire that he may observe, and otherwise direct any fire-fighting operations that may be started. In this district the work has been mainly fire patrol, and consequently the necessity for winter flying has not arisen; but it is anticipated that a standard land machine fitted with skis instead of wheels will be able to meet the conditions.



FIG. 13.

Propeller swinging. Note mat.

WINTER FLYING.

The problems connected with winter flying may be divided into two parts:—

1. Those dealing with the power plant.
2. Those dealing with the rest of the machine.

Power plant problems may be again subdivided as follows:—

- (a) Engine cooling.
- (b) Engine lubrication.
- (c) Engine starting.
- (d) Propellers.

ENGINE COOLING.

Air-cooled Engine.

Any person who has operated an automobile during the winter months in Canada will appreciate the advantages of a satisfactory air-cooled engine. There

is no doubt whatever that when flying becomes general in this country the air-cooled engine will be universally employed, as the difficulties experienced with a water-cooled engine are so numerous that the time occupied in looking after the power plant is excessive. It is, in fact, practically impossible to use a water-cooled engine during conditions of extreme cold, but as in most countries a temporary cold spell may be experienced at any time, it is essential that experience on a water-cooled engine should be obtained even under the most difficult conditions.

With an air-cooled engine there are quite a number of points that require attention and care, more particularly with regard to lubrication.

Water-cooled Engine.

As the standard high-powered aero engines are at present water cooled, it has been necessary during the last few years to determine the most satisfactory

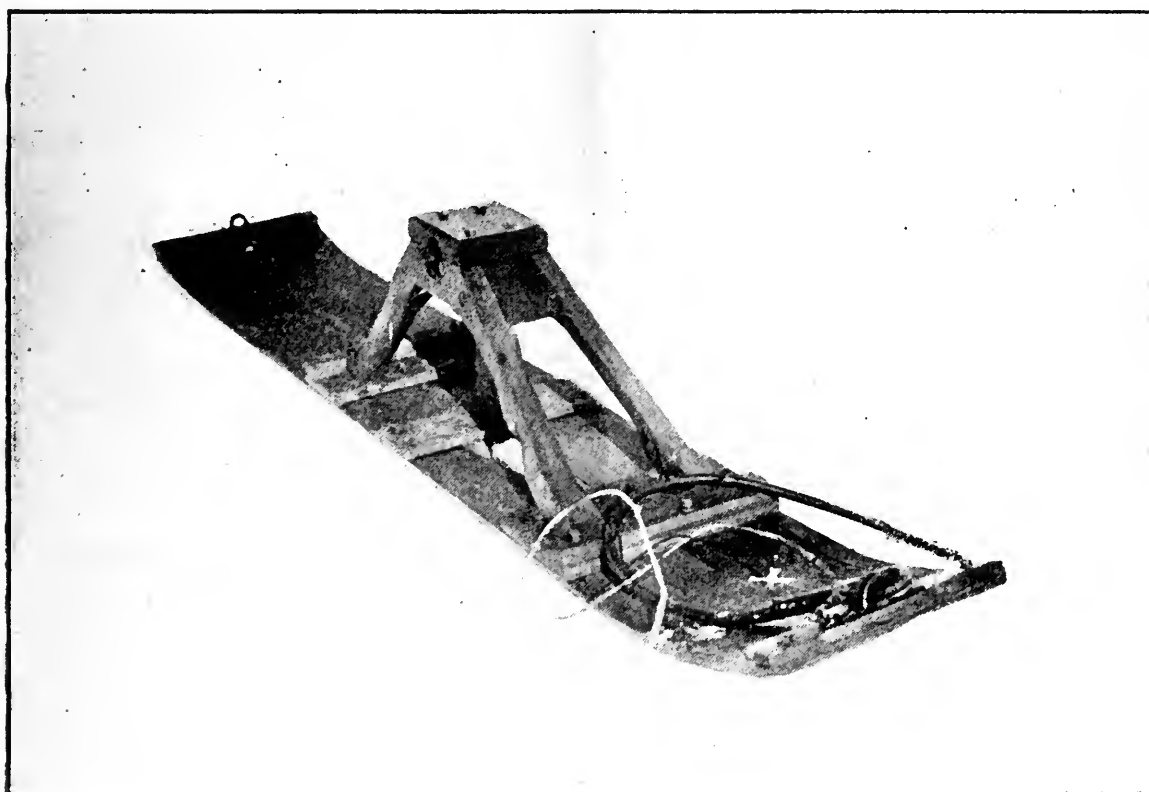


FIG. 14.

Ski for Curtiss machine, as used for training during the war.

way of operating these engines in the winter. To appreciate fully the difficulties that are likely to be experienced it is necessary to consider the case of an aeroplane that is forced to land during the winter at some place where there is no hangar accommodation. On landing it is necessary for the whole cooling system to be drained of water immediately, and in order to be certain that there is no water or ice left in the water pump, or in other parts in the system, it is generally advisable to apply hot-water rags, or some other means of heating, to the system until all draining has ceased. When it is required to again start the engine it is necessary to fill the water system and obtain a free circulation of water without the obstruction of any ice, which is by no means an easy proposition.

Radiator Systems.

If the radiator system of a water-cooled engine is correctly proportioned and is provided with shutters covering the whole area of the tubes, there is usually very little difficulty when the machine has been correctly started up and during the time that it is in flight; but on landing, or stopping the engine, and during the process of filling and warming up from the cold, the present form of honeycomb radiator is likely to cause very considerable trouble. It has been found that any water left in the bottom of a radiator and allowed to freeze causes a fracture of the tube, and the leak is usually not discovered until the machine has been filled again and warmed up for the next flight.

It would appear to be desirable, therefore, to consider the adoption of a radiator system which allows for—

- (1) A variation of area to suit the difference between summer and winter conditions, and
- (2) The adoption of some form of tube system which is not liable to fracture when ice is accidentally formed.

Anti-freeze Mixtures.

A good deal of work has been carried out on anti-freeze mixtures, and owners of automobiles will appreciate the limitations of these mixtures due to the fact that any accidental overheating of the engine drives off the more volatile parts of the mixture and results in leaving a mixture in the system, which is of unknown composition and may be liable to freeze. If a really reliable anti-freeze mixture could be obtained, the difficulties in connection with a water-cooled engine would be very largely overcome, but the mixture must be such that by some simple means, such as by taking its density, it is always possible to determine exactly what amount of alcohol or other substance must be added to bring the mixture back to its original consistency.

Another difficulty with anti-freeze mixtures which has not been thoroughly cleared up is the unknown factor of the effect of the highly inflammable gas which is given off from the cooling system while the engine is running. There are so many fire risks in connection with a gasoline engine that it is always undesirable to introduce a further possible source of trouble.

Cowling.

The cowling for aero engines to be used during winter flying requires to be carefully designed. It must be easily removable by a man working in thick gloves, and the fastenings must be such that they can be handled under these conditions.

Further, in the case of an air-cooled engine the cowling must be so designed that the amount of air passing over the engine can be varied to suit different weather conditions.

ENGINE LUBRICATION.

Oil Tanks.

In cases where aero engines are provided with an oil supply sufficient to last for a considerable number of hours it is very undesirable that the main oil supply should all be in circulation at one time, and, therefore, during the latter stages of the war it was usual for the oil tank to be so divided that one or two gallons of oil were in circulation through the engine and the remainder was simply available for making-up purposes. This method of installation is a matter of absolute necessity when dealing with low temperatures, for when starting up it is necessary to run the engine carefully until a reasonable low oil pressure has been obtained, which would not occur until the oil in circulation

has been warmed up sufficiently. If all the oil in the tank is in circulation, this warming-up process takes up too much time. In some cases it may be necessary to fit lagging to the oil tanks so that when once the oil has been warmed up its temperature can be maintained. This, however, can only be an experimental feature made to suit a particular machine.

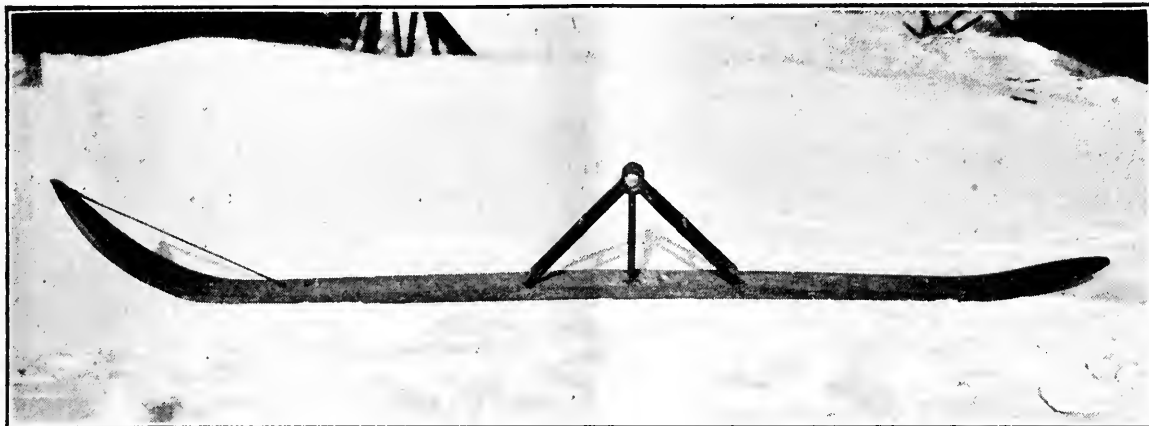


FIG. 15.
Ski for Avro machine.

In some cases it is desirable to arrange for some method of heating the oil tank whilst the machine is standing idle. This saves a lot of time otherwise wasted in heating the oil before starting, but it is difficult to arrange a heater which would be suitable for use when the machine was away from its base. In a hangar the heating can be conveniently done by means of small electric heaters lowered into the oil tank from the filler cap.

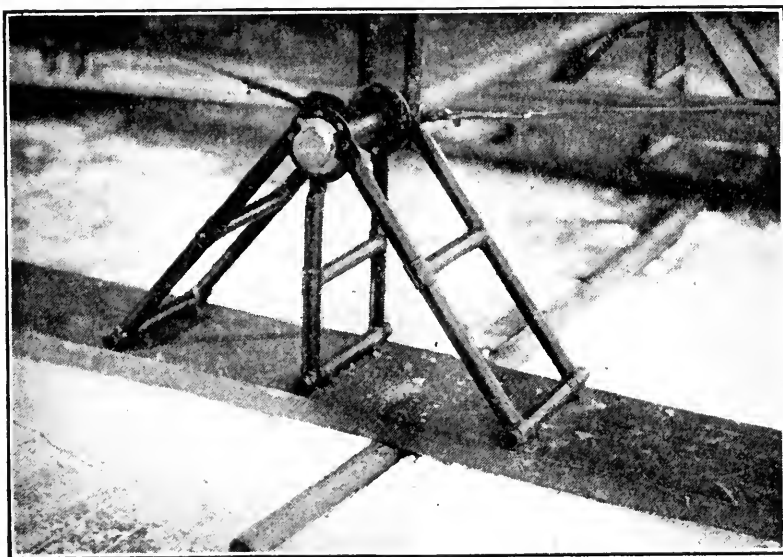


FIG. 16.
Avro fitting slightly modified.

Oil Pumps.

If an aeroplane is forced to remain for any time away from a heated shed it is usually necessary to give some attention to the oil pump. The most convenient way of doing this is usually to drain all the oil pipes, pumps, etc., as soon as the engine has stopped.

If the pumps are allowed to stand without draining, fracture is liable to occur on starting up due to the congealed oil in the bottom of the pump.

Pipes.

From experimental work carried out during last winter it would seem to be desirable to fit some form of pressure relief valve in the oil system to take care of the excess pressures that exist when starting up from the cold.

All pipes should be so arranged that they can be drained through cocks or plugs placed at the lowest points.

Valve Rod Guides.

In the case of rotary engines started from the cold it has been found that the main difficulty has been with the lubrication of the valve rod guides. As a rule these stick up, and in some cases the engine has back-fired into the carburettor due to the inlet valve remaining open. It is always advisable to have a fire extinguisher available when starting a cold engine for this reason.

Oils.

From the usual experience of internal combustion engines it would seem to be probable that aero engines will require a lighter oil for lubrication purposes during the winter, but the amount of work so far undertaken has not been sufficient to allow any standard recommendations to be made yet.

ENGINE STARTING.

To return to the case of the hypothetical machine which has landed during the winter months in some district remote from an aerodrome, it is now proposed to consider the methods that would have to be adopted in order to get the engine started.

Cranking.

When a large engine has been left exposed to a very low temperature it is almost impossible for a man to turn the engine over by means of the hand starting gear, and much worse if he attempts to turn the engine by the propeller. It is, therefore, necessary to take some immediate steps to ease up the engine. With this end in view it has been found desirable to remove all the spark plugs and pour a certain amount of gasoline into each cylinder. Then turn the engine slowly for several revolutions until the pistons have eased up.

In the case of a smaller engine that requires to be turned by means of the propeller it is necessary to remember that in deep snow or on an icy surface the process of propeller swinging is even more dangerous than under ordinary conditions. It is essential that some form of mat should be provided for the man to stand on and also that his footgear is suitable for the existing conditions.

Doping.

In order to provide easy starts under varying conditions a number of experiments were carried out by Professor Robb of Edmonton, and as a result of these experiments Technical Memo. No. 29 was drawn up giving the most desirable mixtures of gasoline and ether for starting the engine under varying temperature conditions. A copy of this technical memo. is given as an appendix.

Ignition.

In the case of an engine provided with battery and coil ignition for starting, such as the Liberty engine, it is necessary that the battery should be removed from the machine at the time that the engine is stopped and kept at a temperature

of normal living quarters until it is required to start again. As it is essential that the battery should be well charged it is considered that a second battery is one of the most useful spare parts to carry. With magneto ignition it is necessary that the contact breakers and distributors should be carefully gone over to see that there has been no condensation and formation of ice. The spark plugs should be removed from the engine just before starting and heated up before being put back into the engine. In some cases it is known that a good engineer has removed the spark plugs from the engine immediately upon landing and fitted an old set, carried for the purpose, in the engine during the time that it was standing. The set of plugs that he proposed to use he always carried with him to his living quarters and kept them near a fire the whole time until they were required for use again.

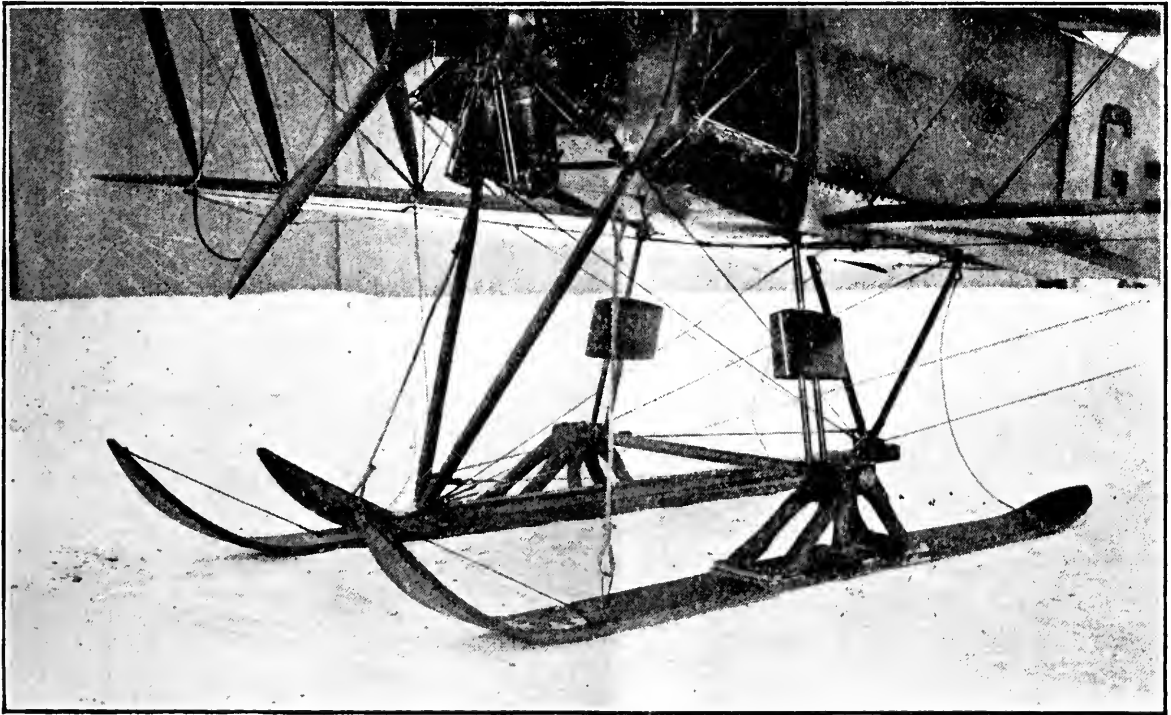


FIG. 17.

Avro ski with Curtiss type fittings.

Filling Radiator.

In the absence of a satisfactory anti-freeze mixture it is necessary to fill the cooling system with water. When setting out to start up the machine it is first necessary to provide an ample supply of hot water, and as soon as the engine has been started and warmed up slightly with the cooling system empty it should be stopped and the radiator system filled.

The process of filling up the cooling system with water is by no means an easy one. If this has not been done thoroughly the machine will probably be forced to land through the obstruction of the system within a very few minutes after leaving the ground. The best guide is, of course, experience of any particular type of machine with its known bad points in the system, but the principle to be followed is roughly given below.

The first thing to do is to open all the drain cocks or drain plugs in the system. These should, in fact, have been left open during the whole time that the machine had been standing. Pour in boiling water at the top of the radiator and allow it to flow through the system until the water leaving is itself very hot. No worse mistake can be made than filling up the system with the bottom plugs

in place as under the condition of extreme cold the water in the bottom of the radiator will always be found to be frozen. When the water issuing from the plugs and drain cocks is hot, pass the hand over all the pipes to see that there are no cold spots in any of the pipes. If a cold spot is found, this is probably due to a local piece of ice, and it will be necessary to thaw it out by means of rags dipped in boiling water or pieces of heated metal. Pass the hand all over the radiator to see that there are no cold spots on the radiator, as it is sometimes found that there will be a channel of warm water in one part of the radiator while the rest is all frozen. As soon as the cooling system is filled, restart the engine and gradually run it up to full speed. If boiling occurs in a very short time it is practically certain to be due to ice in some part of the cooling system, and the engine should be stopped immediately and the cooling system investigated.

Filling Oil Systems.

Before any attempt is made to supple up or start the engine the oil system should be attended to. In most cases it is desirable that when the engine is stopped the oil should be drained completely and the system should be filled with warm oil when starting up. Experience with any one type of machine may modify this to the extent that it may only be necessary to remove the part of the oil which is going to be in circulation, and an oiling system could advantageously be designed so that it was possible to drain the oil from that part of the tank in the circulation of the engine without disturbing the main body of oil. This arrangement of oil tank may be desirable for other reasons as the oil in circulation may be carbonised and required to be renewed when the oil in the rest of the tank is in perfect condition.

PROPELLERS.

Formation of Ice.

It has been found that under certain conditions the propeller of an aeroplane engine becomes coated with a layer of ice along the leading edge. This layer of ice apparently goes on increasing in thickness until a portion of it becomes detached, which at once causes bad vibration of the engine until the remaining pieces of ice have become detached. Up to the present no method of overcoming this difficulty has been found.

Metallic Protection.

For winter flying it is very desirable that a propeller should be sheathed with metal as protection against snow, hail, etc., but it is found that if the metal sheathing is put on in one piece it soon buckles under what appear to be temperature effects. It is essential, therefore, that the metal sheeting should be divided up so that there are no very long lengths without a joint.

WINTER FLYING.

The problems connected with the remainder of the machine may be divided as follows:—

- (a) Landing gear.
- (b) Protection of crew.
- (c) Temperature effects on rigging.
- (d) Shrinkage of wood parts.
- (e) Temperature effects on instruments.
- (f) Temperature effects on shock absorbers.

WINTER LANDING GEAR.

For Aeroplanes.

In a country as large as Canada there are wide variations in the winter conditions that are to be expected. In some districts there will usually be a lot of snow, while in other districts subject to much greater cold there will be hardly any snow at all. It is to be expected, therefore, that in certain parts it will be possible to use wheels, but before attempting to fly from one district to another it is essential to know the depth of snow that is likely to be experienced at the other place.

Districts that have different conditions of snow will also require different forms of winter landing gear. For instance, the skiis as normally used for snow of moderate depth were during last winter found to be quite useless in very deep snow for reasons given below. Skiis have been tried with areas varying

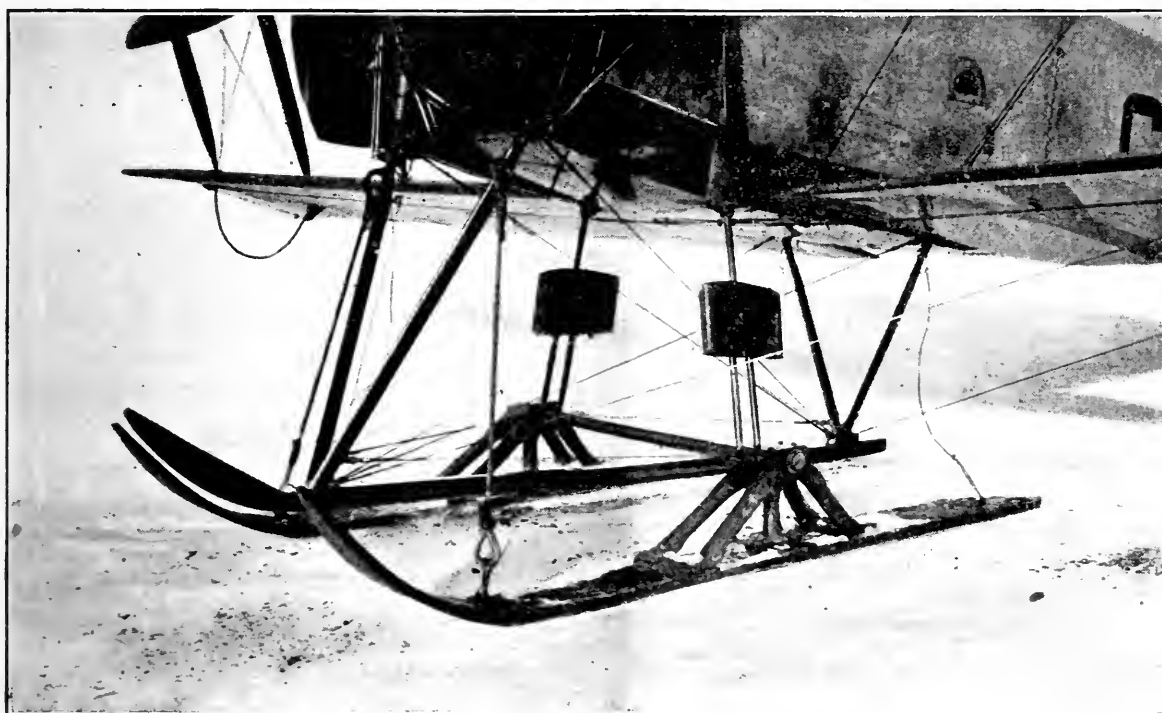


FIG. 18.

Ski reduced in area by cutting off the rear end.

from a loading of 90 lbs. per sq. ft. up to 200 lbs. to the sq. ft., and there is little doubt that for snow of a few inches' depth or for hard surface snow a loading as high as 200 lbs. per sq. ft. can be used satisfactorily.

Skiis require to be of normal form with an aspect ratio such that the length is approximately ten times the width. They should also be sprung; that is, arched at the centre, so that when standing on soft snow the skiis are flat and not bent down in the centre due to the load of the machine. Fore and aft grooves along the bottom surface of the skiis are believed to be of some value in maintaining the direction, but this is very indefinite.

The fitting from the ski board up to the axle should be easily removable, as the bottom boards very rapidly wear out. It is usual to fit check cables fore and aft to limit the rotation of the ski about the axle. These cables should have a length of rubber shock-absorber cord inserted so that they are kept tight under all conditions. One difficulty in connection with skiis is in breaking out when the machine is required to start, as by standing the ski becomes frozen into the surface of the snow. On some occasions it has been necessary to break

out the skis by pushing the tail of the machine sideways, but this is very destructive on the fittings and a much better solution is to prevent the freezing of the skis. Experiments have been made with various kinds of ski wax as usually sold, and it has been found to be satisfactory for this purpose. It is expensive, and some cheaper wax is required.

In designing the fittings for skis it should be remembered that these are liable to be subjected to very large sideloads and especially to a twist when the ski is trying to run straight and the pilot has full rudder on trying to turn. It is considered that ski fittings should be designed for a horizontal load at the top of the fitting equal to half of the vertical load and to the same factor as is used for the vertical load.

In deep snow it is found that a flat board type of ski very quickly buries itself sideways if there is the slightest amount of side drift or turning while taxiing. In fact, in one particular case the machine buried itself up to the wings in soft snow although the ski had ample surface for its support. In order to prevent this digging in sideways it is necessary to have a certain amount of side area, and in consequence of this experience it has now been decided that whenever deep snow is likely to be encountered it will be necessary to use a ski which is much more like a float. In some ways this is not a disadvantage, as it will allow for a certain amount of fairing of the up-turned point, but the introduction of large side area may also require the addition of more fixed fin area at the tail of the machine.

When a machine is equipped with skis it can be handled with more or less ease on a snow or ice surface; but if it is required to be housed in a heated shed some auxiliary means of handling is necessary. For this purpose it has been found that a three-wheeled garage jack, as used for moving automobiles, can be used with advantage, and there is plenty of scope for ingenious means of rapidly fitting wheels for taking the machines in and out of sheds.

An important item not to be forgotten is the fitting of a large spade-shaped ski to the tail skid. This is very satisfactory from the point of view of keeping the tail out of the snow, but owing to the low resistance to sliding a tail ski lacks the braking effect of an ordinary tail skid. It has been suggested that the tail skid should project through the tail ski for several inches so that if there is a crust on the snow the point of the tail skid would break through and give a braking effect to the machine.

In the case of a very sandy aerodrome it has been found advantageous to leave the winter tail ski of the machine for use in the summer so as to avoid cutting up the sandy surface.

Float Seaplanes.

It has been suggested that float seaplanes could be used for winter landing by fitting a ski board to the lower surface of the floats. This, however, does not appear to be feasible owing to the fact that the bottom of the float does not change its angle to the rest of the machine whereas a ski requires very considerable changes of angle.

For a float seaplane it is suggested that the float should be entirely removed and winter landing gear fitted, as it is only for a very short period that the machine may be required to act as an amphibian. During the winter all landing is on snow or ice, and during the summer all landings can be made on water.

Flying Boat.

The flying boat has so many advantages for flying during the summer months that it would appear to be very desirable to provide a winter landing gear of the amphibian type rather than to do away with this type of machine.

This landing gear need not necessarily be convertible while in the air, but can simply be a ski attachment put on at the commencement of the winter. The problem is one which does not seem to involve any great difficulties, and it is certainly well worth trying.

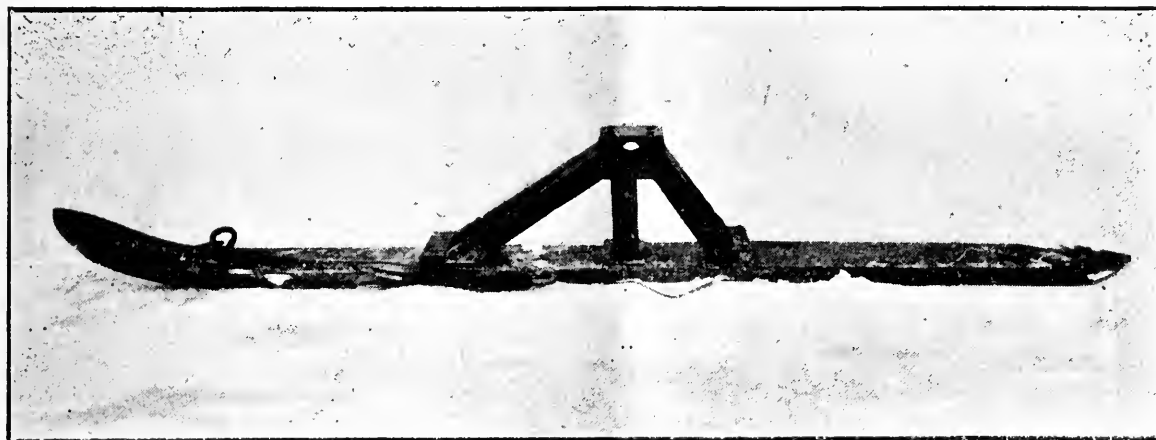


FIG. 19.

Ski further reduced by cutting down the front.

PROTECTION OF CREW.

Enclosed Cabin.

For the protection of the crew of the machine during the winter it is very desirable that some form of enclosed cabin should be fitted, but it is pointed out

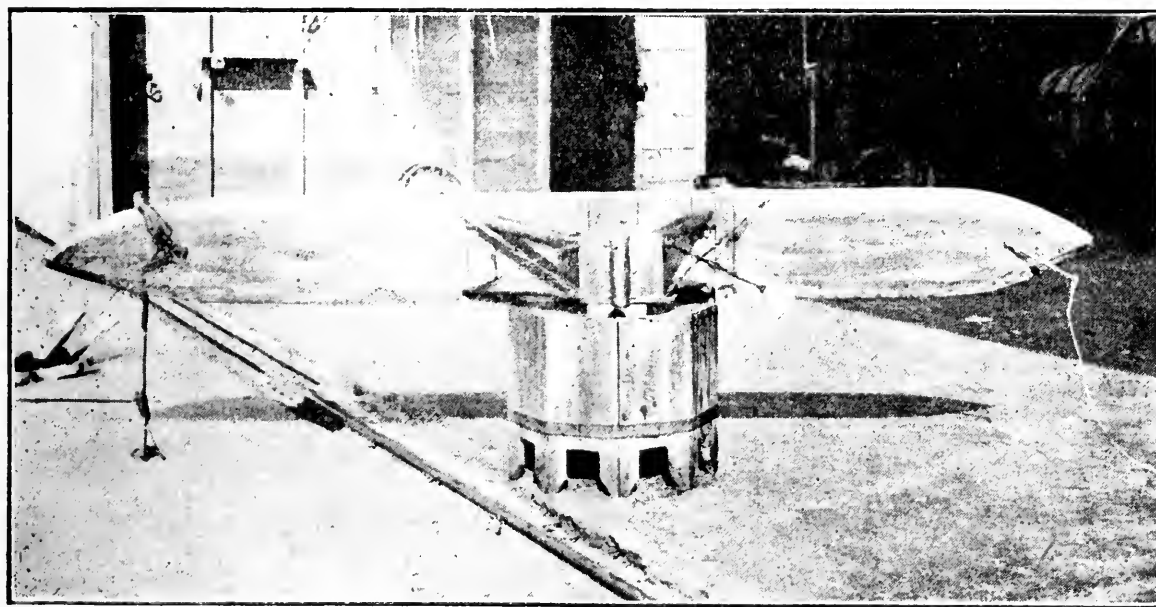


FIG. 20.

Cross bracing added to Curtiss type fitting.

that this cabin requires to be very carefully designed, and further, a lot of experimental work is necessary in this connection.

Experience on the passenger-carrying services in England has shown that the passenger cabin on a machine used for transportation purposes can be correctly ventilated for ordinary summer conditions, but under winter conditions the question of heating and ventilation is a very different problem. The design

of a cabin for members of the crew that are required to operate the machine is even more difficult as it is necessary to provide protection and at the same time give sufficient view and access to the other parts of the machine for the requirements of the crew. Anything in the nature of an ordinary window becomes fogged if the cabin is heated and the outside air is very cold. Therefore, all windows must be capable of being easily and rapidly cleaned.

It is regretted to say that up to the present very little work has been done along these lines, but it is a subject that requires urgent attention if any serious winter flying is to be carried out.

Flying Clothing.

The subject of flying clothing is so closely associated with the question of accommodation that the two must be studied together. If a heated cabin is provided for the passengers, then the flying clothing does not require so much attention; but it must be remembered that sufficiently heavy clothing must be available for the passengers when they leave the machine or in the event of the heating system failing. The old type of electrically-heated flying clothing as used during the war is not at all satisfactory for several reasons. In one type there is a heated coil in the middle of the person's back. If this is kept on, perspiration is often set up. The heater is then turned off, and in a very short time a mass of ice forms inside the clothing in the neighbourhood of the heater so that the person is kept alternately hot and cold. A solution would appear to be best found by providing a cabin which could be maintained at a uniform temperature of about 60°F. and by supplying fur robes for the occupants to wear when leaving the machine or when the heat is turned off.

Helmets and Goggles.

These are very closely connected with the previous two subjects, and should be studied in connection with them. Tinted goggles are necessary to prevent eye strain due to the glare set up from a snow surface.

Emergency Gear.

Any machine flying away from railroads or settlements must be provided with emergency gear for the use of the personnel in the event of landing away from the base. This emergency gear must consist of two or three days' rations, rifle, snow shoes, warm clothing, etc., in order that the personnel can maintain themselves under the cold conditions.

TEMPERATURE EFFECTS ON RIGGING.

It has been observed that there are more failures of streamline wires during the winter months than during the summer, but the reason has not been explained.

Temperature Variations.

If an aeroplane is kept in a heated shed at a temperature of about 60°F. and is then taken out into the open air with a temperature of below zero there will be some quite large stresses induced in the rigging due to the difference in the construction of the wood and metal parts. It has not yet been shown that these differences are sufficient to account for the increased number of failures, but it would appear to be desirable that the machine should be rigged under cold conditions.

This also applies to the case of a machine used for very high flying where the ground may be quite warm, but at a great height the temperature may be very cold indeed. It is not known whether failures have occurred in Europe under these conditions. It is hoped that some low temperature vibration tests on wires may also throw some light on this matter.

Metal Construction.

From the point of view of rigging and alignment, the advantages of metal construction would appear to be very great when a machine is likely to be subjected to extreme variations of temperature, but before the light alloys can be adopted with confidence it is desirable that experiments on vibration of light alloys at low temperatures should be carried out.

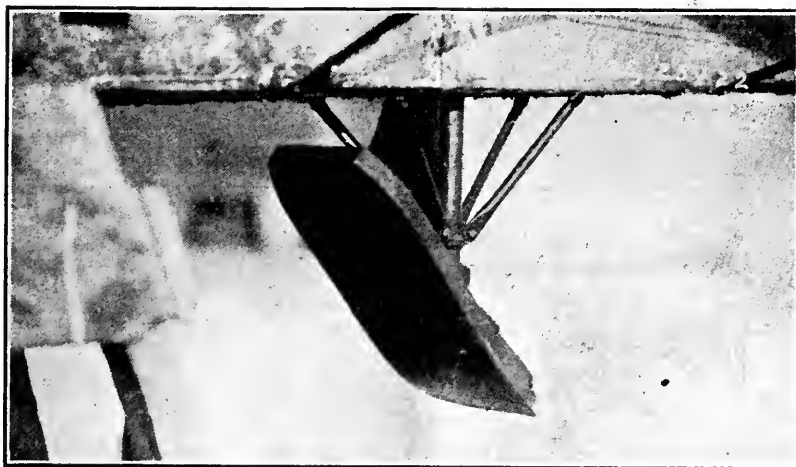


FIG. 21.
Tail ski.

SHRINKAGE OF WOODEN PARTS.

When subjected to very low temperatures the air becomes abnormally dry, and it has been found that, however well protected with varnish, wooden parts tend to dry up and shrink. This condition is also found during the summer

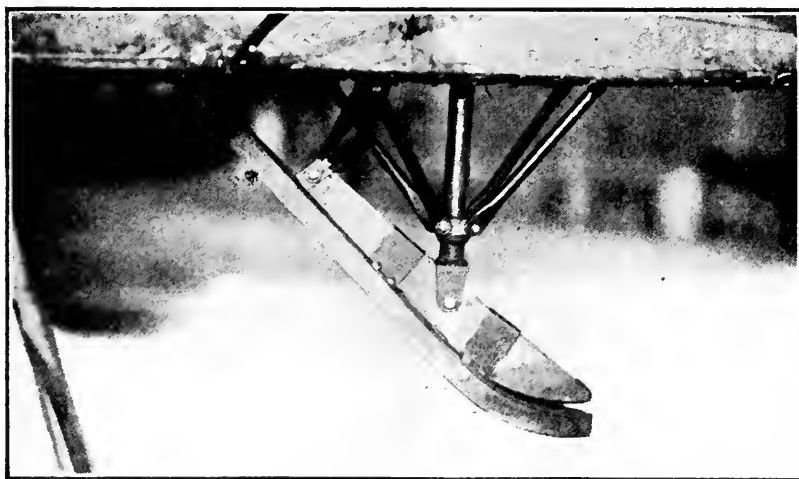


FIG. 22.
Tail ski.

months in the prairie country, and therefore it would seem to be necessary that while wood is still used in aeroplane construction, the parts should be manufactured in the district in which they are required to be used. It has been found that a wooden spar of about $3\frac{1}{2}$ inches' depth will contract in depth sufficiently to break the flanges of all the ribs, or to pull away from all the ribs, with the result that it becomes imperative to open up planes at least once a year to see the condition of their spars and ribs.

It is also found that all metal fittings encircling wooden parts become loose and require tightening. This difficulty with the use of wood is another very strong reason in favour of metal construction, and with this end in view it is desirable that as much experimental information on metal construction should be obtained as possible.

TEMPERATURE EFFECTS ON INSTRUMENTS.

Air Speed Indicators.

Owing to the difficulties experienced with rubber under low temperature conditions it was anticipated that an air-speed indicator with a rubber diaphragm

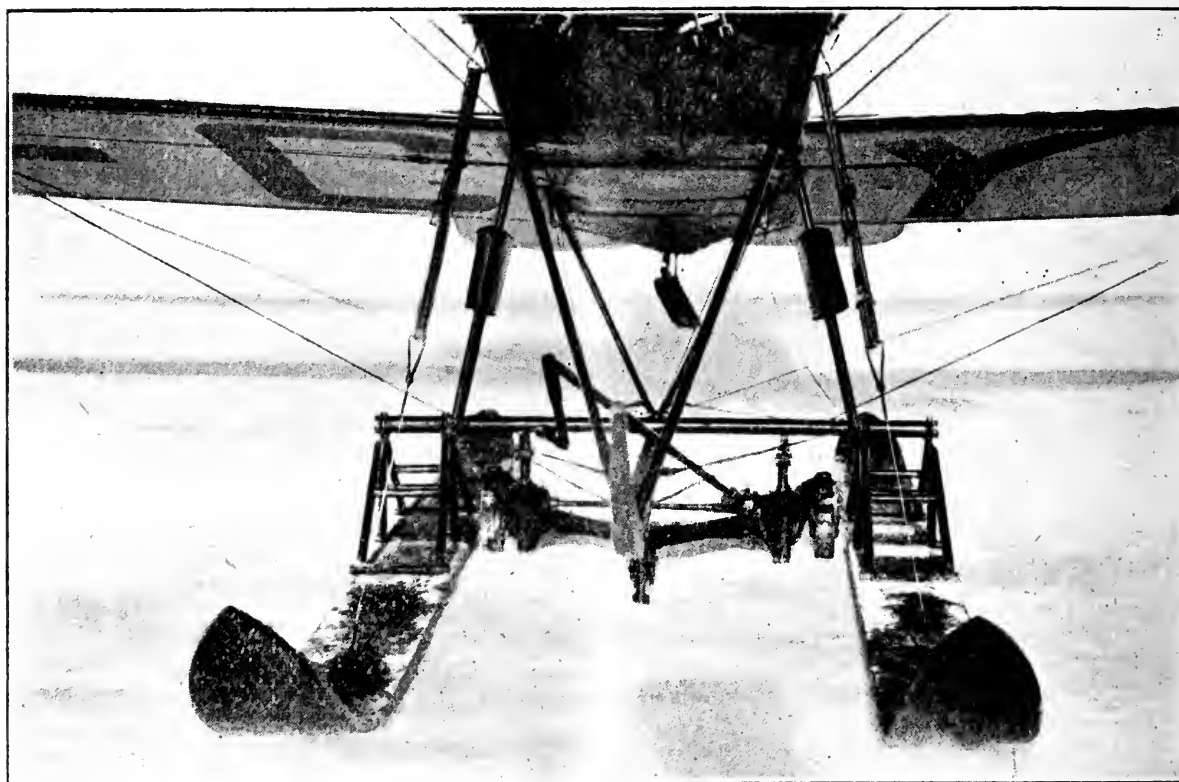


FIG. 23.

Garage jack for handling in sheds.

would be unsatisfactory. Some tests were carried out to investigate this, and it was found that although a rubber diaphragm air-speed indicator was a little sluggish at low temperatures it did not actually cease to function until a temperature of -60°F . was reached when the diaphragm ceased to work. From this it would appear probable that a rubber diaphragm air-speed indicator would not usually give any trouble at the temperatures likely to be met, but it has been found that an occasional air-speed indicator of this type will cease to function. At a temperature of around 0°F . this effect is believed to be due to the mechanism rather than to the diaphragm. A comparison carried out between a steel diaphragm indicator and a rubber diaphragm has shown that more reliable results can be obtained from the steel diaphragm indicator as it is less sluggish, the readings up and down the scale are more nearly the same, and no temperature effect down to -100°F . has been found.

The possible stoppage of the usual form of pitot head by ice must also be considered, with the result that it will probably be necessary to use a ventive tube with orifice sufficiently large to prevent stoppage.

Revolution Indicators, etc.

No bad defects of these instruments have yet been reported, but it is anticipated that lubrication troubles, particularly with long flexible shafts, are likely to be experienced.

Temperature Effects on Shock Absorbers.

When landing on ground under cold conditions it is found that there are more failures of shock absorbers, axles, etc., than in the summer. This may be attributed to one or both of two causes:—

1. The hardness of the ground.
2. The temperature effect on rubber.

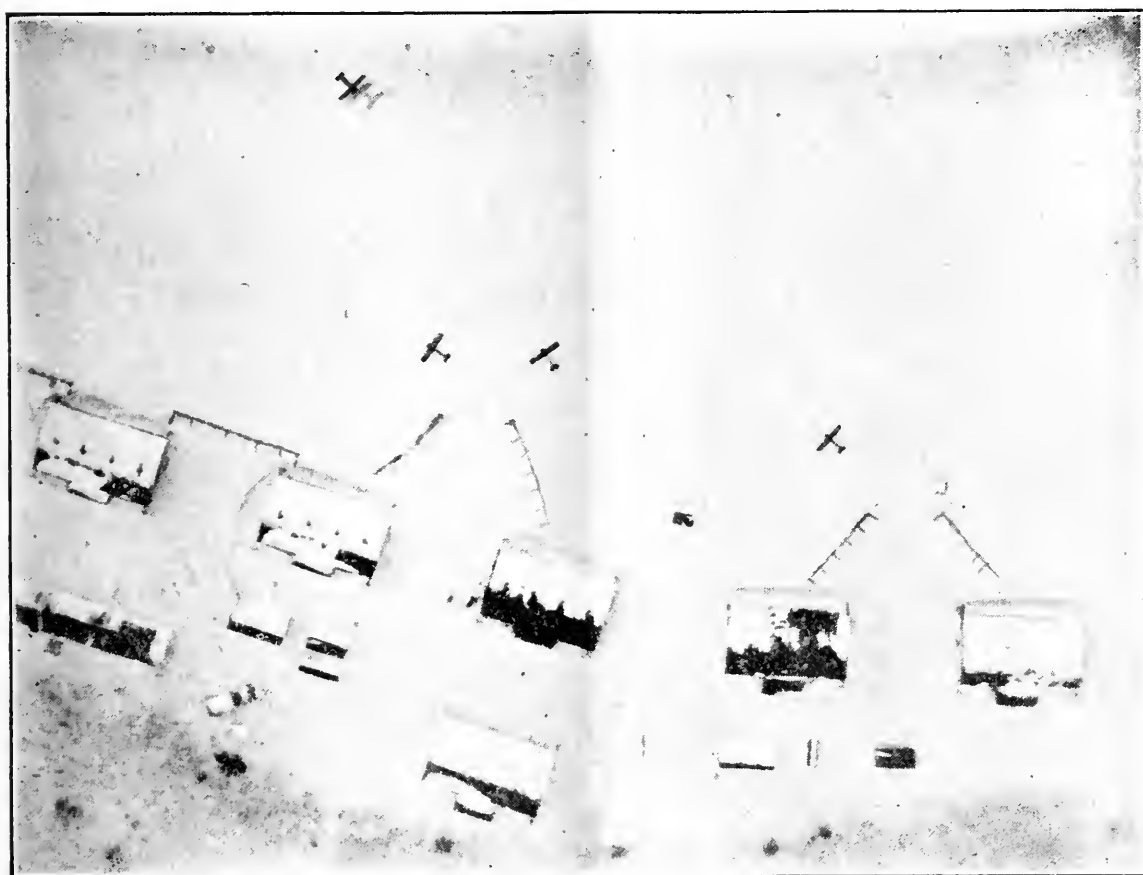


FIG. 24.

Snow fences around hangars.

In order to determine the effect of temperature on rubber shock absorbers some experiments have been started on the qualities of this material under low temperatures, and it is anticipated that it will be necessary to rewind shock absorbers for use in the winter.

LANDING ON SNOW.

It has been found to be very difficult to judge the height of the machine when landing on a clear snow surface, and, therefore, if flying is to be carried out around an aerodrome it is essential that the surface of the snow should be cut up by taxiing the machine around the aerodrome before flying commences. In the case of landing on a snow surface which has not been cut up it is necessary for the pilot to take as much advantage as possible of any surrounding objects, such as trees, in order to get an indication of the height above the

ground. This effect will, of course, be the same as that experienced with landing a seaplane on water which is perfectly smooth.

Snow Fences.

There will, of course, be a large number of other questions dealing with snow conditions which require attention. A particular case is the necessity for the prevention of snow from drifting up around the hangar doors, and some form of snow fencing is usually necessary to prevent this.

CONCLUSION.

Up to the present it has not been possible to do more than to consider the problem of winter flying and to start such researches as circumstances permit. The Honorary Advisory Council for Scientific and Industrial Research formed an Associate Air Research Committee, and it is due to this Committee that the research work mentioned above has been carried out.

In addition to this a good deal of the experimental work on winter flying has been carried out at Camp Borden under the direction of the Officer Commanding, Canadian Air Force.

APPENDIX.

THE AIR BOARD.

OTTAWA, ONT.

TECHNICAL MEMORANDUM No. 29

(Cancelling Technical Memos. Nos. 2 and 15).

Re Starting Aero Engines at Low Temperatures.

The work carried out by Professor Robb at Edmonton during this season and last can now be summarised in the form of a procedure for starting aero engines at various low temperatures.

The problem, as presented to Professor Robb, was that he was to assume that the engine was in an aeroplane which was forced to spend a night in the open away from the base, and it was desired to know the best method that the crew should adopt in order to start the engine the following day.

It is assumed that while the engine has been still hot the cooling system has been completely drained, or that an efficient anti-freeze mixture is available. It is also assumed that the battery has been removed from the machine and kept at ordinary room temperature, and also that a supply of commercial ether at room temperature is available.

The first operation is to ease up the motor by doping with about one half-pint of gasoline and turning the engine over until it is quite free. In this connection it is important to see that there is no ice in the water pump before any attempt is made to turn the engine over.

The next operation is to dope the engine with about one quarter of a pint of a mixture of ether and gasoline. The mixture which is most suitable to different temperatures is given in a list below.

It is important that this initial doping should not be too liberal as it has been found that if the doping is slightly increased the engine does not start well.

As soon as the engine starts to fire, an additional one quarter of a pint of the mixture is pumped into the intake manifolds, and this should suffice for the engine to begin to fire on gasoline from the carburettor, which has been flooded meanwhile.

The motor is allowed to run for about two minutes until it is warm enough to take water at ordinary room temperatures, but care must be taken that the engine is not run too long without water.

As soon as the cooling system has been filled the engine should be started again and run for some little time to see that the cooling system is functioning properly.

If the engine starts to boil in an unduly short time, examination should be made for an accumulation of ice that may have stopped the system.

Experiments will be carried out on the best method for handling the oiling system, but at present it is considered advisable to drain the engine immediately on landing and fill it up with oil at at least room temperature when commencing to start. It is essential that the battery should be charged to specific gravity of over 1.25, and this suggests an extra battery should be carried. (The experiments were carried out on a Liberty engine. If the engine is fitted with magnetos, care should be taken to see that the contact points and the distributor are clean and in good order before attempting to start.)

The priming nozzles serving the intake manifolds must be sufficiently large to permit liberal doping quickly, and in the case of a second cold start being required soon after the first, care should be taken to see that these nozzles have not become frozen up.

The priming device requires to have sufficient capacity to permit quick doping with ether mixture, and the storage tank to serve the priming pump should have capacity for at least one half-pint of mixture to permit two dopings.

Professor Robb used a pump constructed from a grease gun which had a bore of $1\frac{1}{8}$ ins. and a stroke of 7 ins., and he states that a standard priming pump is too slow for this particular service.

Professor Robb experienced no difficulty with the spark plugs in almost 100 starts, but it is considered advisable to remove the plugs from the engine and heat them over a fire before attempting to start.

The proportions of the mixture for doping, suitable for different temperatures, is as follows:—

Temperature.	Gasoline.		Ether.
+20°F. and above.	Pure.		
Zero to 20°F.	3	to	1
—15°F. to Zero.	2	to	1
—30°F. to —15°F.	1	to	1
—37°F.			Pure (Warm).

At the higher temperatures it has not been necessary to warm the mixture, but a start at —37°F. indicates that at this temperature ether requires to be warm, that is, at room temperature. The carburettor should be flooded in all cases before starting, and the spark should be advanced immediately the engine begins to fire. The usual position of the throttle for starting the Liberty engine is about $1/5$ th open.

The ether used in these tests has been put up in one pound sealed tins marked "Mallinchrodt Motor Ether."

In connection with this research a number of interesting points have been raised, and it is suggested that if any further information is required, application should be made to the Secretary of the Air Board.

(Sgd.) E. W. STEDMAN,

Director of Technical and Stores' Sections.

CORRESPONDENCE.

To the Editor of the AËRONAUTICAL JOURNAL.

DEAR SIR,—With reference to Captain de Haviland's very interesting paper on the Design of a Commercial Aeroplane, reported in your last month's issue, I should like to make the following comments upon the author's attitude towards all-metal aircraft.

Firstly, I can quite understand that there is no argument for immediately introducing all-metal machines into these services. Captain de Haviland and Mr. Handley Page are both engaged in the very difficult problem of making commercial air services financially successful, and since wooden built machines are quite satisfactory for their present requirements, there is no reason to "swop horses in the middle of the stream."

This fact, however, is no argument for belittling the merits of all-metal construction as a whole, nor for assuming that it will be many years before the all-metal machine replaces the old type of construction.

At the present time my firm is in the unique position of being the only firm in this country which has built and flown an all-metal aeroplane, and I am therefore able to speak from actual experience.

Our machine was designed, built and flown within the space of six months, which is sufficient refutation of the idea that all-metal machines are difficult to build. Broadly speaking, I should put down the advantages of our all-metal machine as follows:—

Greater strength for a given weight of structure, less liability of damage to the structure in the event of a bad landing, absolute fireproofness, greater rigidity of the plane surfaces, which becomes increasingly important in view of the high speeds (and consequently high air pressures) which are being attained to-day. The ease with which fireproof bulkheads are inserted in the fuselage, great cleanliness of design, permitting of ready inspection of the interiors of planes and fuselage. (It is possible to take off a plate of the wing covering and replace it in a very short space of time, roughly thirty to forty-five minutes.)

It is quite certain that a metal monocoque fuselage lends itself more readily to mass production than does a wooden fuselage of the same type, whilst it is less likely to be damaged and easier to repair in the event of damage.

We found that we could build our fuselage in several separate segments, completely finishing the details of these segments and then rivetting them together in a very short space of time.

Finally, there is the undoubted fact that an all-metal machine will weather better than one of wood and fabric.

So far as fighting aircraft are concerned, I am convinced that the all-metal machine will entirely replace the older form of construction and that in a very short space of time.

I do not wish to create any misunderstanding as regards the weight of metal-covered plane surfaces; it seems to me that it will always be possible to build a plane with metal structure covered with linen fabric, lighter than a similar plane covered with sheet metal, but the difference is not so great as some people imagine, it is about 2/10ths-lbs. per sq. ft., and this figure is capable of reduction in the future when thinner gauges of metal are made.

Yours faithfully,
OSWALD SHORT.

Whitehall House,
29-30, Charing Cross, London, S.W.1,
11th August, 1922.

[Further correspondence on the all-metal aeroplane is invited.—EDITOR.]

REVIEW.

The Airplane Engine. By Lionel S. Marks (Professor of Mechanical Engineering, Harvard University). McGraw-Hill Book Co., Ltd. 30s. net.

The great struggle between the belligerent nations for supremacy in the air during the war can be truthfully stated to have been largely concentrated around the development of high performance and reliable types of aircraft engines.

In order to accomplish the results attained, which under normal conditions would probably have taken at least three or four times as long, a tremendous amount of development and research work was necessary.

This work was almost exclusively carried out under the auspices of the various governments concerned; but owing, however, to the conditions under which it was conducted and the veil of secrecy with which it was naturally shrouded, the results obtained were not available for publication until the last year or two and then only in disconnected form in the shape of many important papers given before the various learned societies or in the pages of the various periodicals which make a feature of this type of work.

Professor Marks is therefore to be congratulated on this volume, which in his introduction he states attempts two things, viz.:—"To formulate existing knowledge of the functioning of the airplane engine and its auxiliaries; and to present and discuss the essential constructive details of those engines whose excellence has resulted in their survival," and which does in effect summarise and present in a very readable and comprehensive form the conclusions reached as a result of the research work previously referred to.

The book contains nineteen chapters, a good index and 349 illustrations, and a total of 454 pages.

The illustrations are particularly good, comprising as they do many detailed working drawings and diagrams of some of the most modern aircraft engines of all types and of all nations.

The first three chapters deal with the power required for flight, engine efficiencies and capacities and engine dynamics respectively.

The next chapter, which treats of engine dimensions and arrangements, deserves special mention, as it contains a series of tables which cannot fail to be of great value to designers and all other workers connected with the aircraft engine industry, viz., full particulars of the general and detailed dimensions of various types of modern aircraft engines selected for their proved reliability and performance.

The subject of materials is next dealt with, and as it is a well-known fact that it is largely the enormous strides made with materials, especially alloy steels and aluminium alloys, that have made the modern aircraft engine possible, the particulars given of the materials recommended for all engine parts are of great interest.

The design of engine details, valves and valve gear and a general discussion of radial and rotary engines are next considered, and it is interesting to note in connection with the last-mentioned chapter, the pre-eminence of the air-cooled static radial engine, a design which has been largely fostered by the British Government and which undoubtedly gives higher performances from the power-for-weight point of view than any other type of aircraft engine.

In view of the necessity for utilising high compression ratios in modern aircraft engines in order to obtain efficiency, the subject of fuels and explosive mixtures which is next dealt with is of very great importance and is one around which discussion centres very largely nowadays. It is pleasing to note, therefore, that

the work of Ricardo, who has done so much towards eliminating the trouble with "detonation" or "pinking" experienced when using standard fuels in high compression engines, is given prominence.

The carburettor, fuel systems, ignition, lubrication and the cooling system are next dealt with. The last-mentioned chapter is of particular importance, including as it does a very useful discussion on air cooling and details of the design of fins for maximum efficiency. A large amount of research work on air cooling has been carried out during the last few years, especially by the British Government; but a lot remains to be done before it can be definitely stated that air cooling is preferable to water cooling in all fields, although for certain purposes, *e.g.*, the high performance military machines, the air-cooled engine has the preference.

The last few chapters are devoted to geared propeller drives, supercharging, manifolds and mufflers, starting and potential developments.

The chapter on supercharging is of great interest, for the loss of power with altitude, which is a feature of the internal combustion engine, is a great drawback from the military point of view, and most nations have concentrated on researching into the possibilities of maintaining engine power from ground level to a pre-determined altitude.

The chapter on potential developments is a general review of the situation regarding aero engine design as it stands at present and an indication of possible developments in the future, which should serve as a stimulus to research workers and designers to carry on the good work of developing the aircraft engine until it is thoroughly reliable and can be truthfully stated to be the means of ensuring cheap and reliable transport by air.

F. A. F.



THE AËRONAUTICAL JOURNAL.

(FOUNDED 1897 in succession to the ANNUAL REPORTS.)

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 142.

OCTOBER, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

New Chairman.

On the termination of the term of office as Chairman of Lieutenant-Colonel Mervyn O'Gorman, C.B., Professor Leonard Bairstow, C.B.E., F.R.S., becomes Chairman of Council on the first of this month for the year 1922-1923.

Election of Members.

The following members were elected at a Council Meeting held on Wednesday, September 13th:—

Associate Fellow.—Miss H. M. Lyon.

Student.—H. A. Sherwin Gothard.

Presentation of Awards.

The Society's Silver Medal will be presented to Mr. H. R. Ricardo, and the Pilcher Memorial Prize for Students to Mr. S. H. Evans at the commencement of the first meeting, to be held at the Royal United Service Institution on Thursday, October 5th, at 5.30 p.m.

Journal.

Among the advertisement pages will be found a classified list of the articles which have been published in the Journal during the last five years, which it is hoped will prove of value for reference purposes. A number of copies of this list have been printed off as a leaflet, and members will greatly assist if they would forward to the Secretary the names of anyone they think likely to subscribe to the Journal to whom this leaflet might be sent.

In connection with this, the following quotation from a letter recently received from America is of interest:—

"I congratulate you and the Society on the continued excellence of the AERONAUTICAL JOURNAL, which is to-day quite the only aeronautical publication which is worth reading carefully."

Library.

The following books have been received and placed in the library:—"Fuel for Motor Transport," Second Memorandum, by the Fuel Research Board. "A Short Course in Elementary Meteorology," by W. H. Pick. "Proceedings of the Second Air Conference, held on 7th and 8th February," Air Ministry. "All

the World's Aircraft," edited by C. G. Grey. "Aeronautic Papers," by J. H. Parkin. "A Dictionary of Applied Physics," Vols. 1 (Mechanics, Engineering, Heat) and 2 (Electricity), edited by Sir Richard Glazebrook. Reports of the First International Air Congress (Paris, 1921). "Report on Ex-German Aerodromes and Material in Back and Occupied Areas," by the Inter-Allied Aeronautical Commission of Control. "Aviation in Peace and War," by Sir F. H. Sykes. "Application de la Resistance des Materiaux au Calcul des Avions," by M. Boileve. "The War in the Air," by Sir Walter Raleigh. "14,000 Miles Through the Air," by Sir Ross Smith. "Steel Thermal Treatment," by J. Urquhart. "H. G. Hawker, Airman," by M. Hawker. "Theory of Wave Transmission," by George Constantinesco.

Forthcoming Arrangements.

- Oct. 5, 5.30 p.m.—Royal United Service Institution. Prof. L. Bairstow, "The Work of S. P. Langley." Presentation of Awards.
- „ 11, *Scottish Branch*.—Annual Meeting. Mr. Sholto Sheppard, "Proposed Solution of Aerial Transport Problems." Mr. A. A. Sidney, "The New Beardmore Engine."
- „ 12, 6.45 p.m.—Society's Library. Students' Section. Annual Meeting and Election of Officers.
- 7.30 p.m.—Inaugural Address by Dr. A. J. Sutton Pippard; Chairman, Lieutenant-Colonel W. Lockwood Marsh. (This meeting is open to all members of the Society.)
- „ 17, 4.0 p.m.—Library and Publications Committee.
- 4.30 p.m.—Candidates' Committee.
- 5.0 p.m.—Council.
- „ 19, 5.30 p.m.—Royal United Service Institution. Mr. J. D. North, "The Metal Construction of Aeroplanes."
- „ 24, *Scottish Branch*.—Sir Sefton Brancker, "Air Transport To-Day and To-Morrow."
- Nov. 2, 5.30 p.m.—Royal Society of Arts. Major A. R. Low, "A Review of Airscrew and Helicopter Theory, with Aeroplane Analogies."
- „ 9, 7.30 p.m.—Society's Library. Students' Meeting. "Airships," by Mr. H. C. Brown. Chairman, Lieutenant-Colonel W. Lockwood Marsh.

W. LOCKWOOD MARSH, *Secretary*.



WILBUR WRIGHT LECTURE.

The tenth annual Wilbur Wright Memorial Lecture was delivered at the Royal Society of Arts, at 5.30 p.m., on Thursday, June 15th, 1922, by Lieut.-Colonel A. Ogilvie, C.B.E., Fellow.

SOME ASPECTS OF AERONAUTICAL RESEARCH.

It was the wish of the Council of the Royal Aeronautical Society that this year's Wilbur Wright Memorial Lecture should have been prepared and read by an American, in order that the practice of drawing the annual lectures alternatively from Great Britain and America might be more firmly established as a custom.

Unfortunately the arrangements made for this fell through, and you will therefore have to put up with one who, though fully conscious of the eminence of his predecessors, is proud that he has been granted this opportunity of showing his respect and affection for Wilbur Wright.

Wilbur Wright.

When ten years ago a telegram came from Orville saying that Wilbur had died I felt as if I had lost an elder brother, who was not only a past-master on the subject of flying, a master willing and anxious to impart anything he knew, but also one who would give careful, painstaking and entirely unselfish consideration to any matter, however unimportant. I never knew him to give a hasty or ill-considered judgment about anything or any person.

It was in December, 1908, that I first met him, when he was at Le Mans, demonstrating to the European public at large, and to the French in particular, that the doubts and suspicions with which the statements of themselves and their friends had been received were without foundation and that real flying was an actual accomplished fact.

I had gone to France in order to learn as much as possible about the design and construction of an aeroplane before setting out to build one of my own, and after visiting the Salon and the works of all the notable constructors, went out to Le Mans to see the Wright machine.

There were a thousand or more people waiting at the aerodrome on the chance of seeing something, and after an hour or two, before our eyes there actually happened what we had heard about but had only half believed. My diary reads as follows:—

“W. Wright made two wonderful flights in afternoon, all kinds of evolutions, turning, skimming close to ground, gliding without engine from 200 feet. A true and complete flying machine. No chance of speaking to Wright.”

Returning a few days afterwards, I arrived to find Wright circling the aerodrome for the Michelin Cup. After a time he was brought down by some small defect in the oiling system.

A mere trifle had prevented him from making a two-hour flight which would have marked for him an important stage, and there was only one more day to go before the end of the year. Nevertheless, while packing the machine away into its rough shed, deciding upon and carrying out a cure for the lubrication trouble, he was quite calm and unhurried.

After everything was in order for the next day we had a long talk, walking about the frozen aerodrome and discussing his plans and mine. One could not help being impressed by his absolute honesty, sincerity and self-control, as well as by his obvious intellectual powers, and I conceived a very great admiration for his character.

It was impossible to evade the thought that he was a man apart, and so I always thought him, notwithstanding the growth of our personal relations into a very warm friendship.

The genial warmth of this I should like to illustrate by a little incident which happened at Eastchurch in 1911, when he was stopping in camp with me and helping to get my little racing machine ready for the Gordon Bennett.

We were running the engine in the shed with the doors closed, and Wilbur was testing the propeller revolutions by counter and stop-watch. He was wearing a bowler hat, and when withdrawing his head and shoulders through the front spar bracing, managed to get the hat knocked off his head by a wire. It rolled across the plane and was caught by the propeller, flew round the shed, came back into the propeller stream and made a second circuit, finally coming to rest in a corner. After this trip the hat was considerably dented, so we bought him a new one in exchange.

* The following reference from a letter shows the pleasant humour and kindly spirit which so endeared him to his friends:—

“ P.S.—When I came to settle accounts with Mr. Brewer I found several disputed accounts, in one of which he claimed you were the only person interested. I claim that if an old hat increases in value in proportion to the number of holes put into it that I have a right to see if there is any possible chance of getting in one or two more before trading it off ! ”

The Foundations of Knowledge.

One of the main points which I want to bring out in this paper is that Wilbur and Orville Wright based the whole of their knowledge on solid foundations, and that if they had not done so it would not have been possible for them to have overcome the difficulties which they encountered before they demonstrated to Europe and to America that real flight was an accomplished fact. It is my firm belief that without that demonstration and inspiring example, the aeroplane as we know it to-day would not exist.

It is also my firm belief that our rapid technical development during the war period, in which we as a nation overtook both friends and enemies after starting a long way behind, was mainly due to the solid research work which was done in the laboratories of this country between the years 1909 and 1914.

It appears to me, however, that there is some danger that the real lessons of the past have not been understood and taken to heart, and I therefore take leave to conduct you again over some old ground that we may see if there is not something there which will help us in laying our plans for the future.

It has been generally accepted that the Wrights were experimenters who grasped the essentials of the problem of flying, as it was then known, and tackled them in a practical and intelligent way. Also that they were the real and true pioneers of mechanical flight in December, 1903.

But there are still men, eminent and distinguished men, who believe that this success was really due to the superior flying skill and technique of the two brothers. They do not appreciate that it was a demonstration of something bigger and more important even than that—a demonstration of a firm structure of knowledge based on experimental work of the most solid kind.

It is greatly to be deplored that it has not been possible to publish the results of the wind-channel work which was done in the workshop at Dayton after the 1901 gliding was over, because the actual figures of these experiments would have dispelled the last doubt.

However, a study of the results attained affords to an aeronautical engineer evidence which should be sufficient to convince him.

Take the small racing machine which in 1910 the Wrights produced to compete in the Gordon Bennett Cup and compare it with their standard machine of that date, and it is obvious, even more so now than it was then, that both machines were designed on a scientific basis founded on definite data. Table A gives the main figures for the two machines, so that they are easy to compare.

You will notice that the aspect ratio is about the same in both machines, *i.e.*, about 6 to 1, and the gap chord ratio about 1, both of which features are still standard practice to-day.

The bold increase in the surface loading from $2\frac{3}{4}$ to 6 lbs. per square foot should also be noted.

I was in Dayton during the time the small machine was being designed and built, and saw how reference was continually being made to little pocket-books, in which were collated the results of the wind-channel research work carried out mostly during the winter of 1901-1902.

It was known that the French flyers would be sending over a strong team to capture the cup and that they would be using the new 70-h.p. Gnome, an engine of good power for weight, and one which was considered in those days to be a very formidable proposition and by many almost too powerful for a single-seated machine. This may be amusing to my present audience, but I would remind them of the excitement when the 50 Gnome was put into the Bleriot monoplane in place of the 25 Anzani.

The Wrights made up their minds that they would have to double the speed of their standard machine in order to win. They were much behind time, and had to make the utmost use of their standard equipment. They therefore designed and built a machine of less than one-third the area, two-thirds of the weight and double the power of their standard machine.

When first flown by Orville the machine came up to its designed performance—was in perfect balance and control.

It is doubtful if any aeronautical designer of the present day, with all the increased knowledge now at his disposal, could make so immediate a success of so radical a departure.

It has been my fortune to have had a great deal of experience in the trials of new designs of aircraft and to have watched many through their teething troubles, but looking back on that performance of twelve years ago it is evident that a very full knowledge of design data was available to the Wrights at that date.

History of Experimental Work.

To get a grasp of the processes of research and technical development, through which Wilbur Wright and his brother passed, it would be as well to recall briefly the history of their experimental work, looking at the matter from this particular angle. In 1900, after absorbing all available information on the subject of flight and following particularly the path indicated by Lilienthal, they built their first glider with biplane wings 18ft. span by 5ft. chord, incorporating a warping device for lateral control and a front elevator for fore and aft control.

Some of you might be interested to hear how this warping device was thought of.

The Wrights knew that they wanted to give different angles of incidence to the two wing ends to obtain the lateral control which they saw from accounts of previous experiments was necessary. Wilbur was explaining to an interested audience what was wanted and was using an old open-ended cardboard box,

which had probably contained puffed wheat or some other strange American breakfast food, to illustrate his remarks. As he was holding it by the two ends and twisting it about, he suddenly realised that in his hands he had a biplane structure firmly braced in two planes but able to be twisted at the two open ends, and that this was just what was wanted for the lateral control of a flying machine. In the first machines the warping wires ran in the fore and aft direction and not forming the bracing of the back spars in a lateral direction as we used to know them.

The elevator or horizontal rudder as it was called was another new device worked out to meet another well-known difficulty, that of controlling the movement of the centre of pressure. The front part was fixed, and the back edge could be moved up and down. The effect was that in the neutral position the plane was flat, while a movement of the back edge gave it a curve upwards or downwards with an increasingly powerful action either way.

On trial, the 1900 machine did not come up to expectation. The resistance or drag of the planes was remarkably low, but the lift did not come nearly up to the figure deduced from Lilienthal's tables, upon which the machine had been designed. The lateral and fore and aft controls were very powerful, and were thought at this stage satisfactory.

The next year exactly the same type of machine and arrangement was followed, but the area was nearly doubled. It should be noted that the aspect ratio of both these gliders was little more than 3 to 1.

At first this 1901 machine could only be controlled with extreme difficulty, as it insisted on climbing steeply or diving. The full control had to be used to prevent an accident. The trouble was eventually traced to the big camber of the main planes causing excessive movements of the centre of pressure and stalling. After this was cured some good glides were obtained. Octave Chanute was stopping at the Wrights' camp and told them that they were well in advance of any other experimenters. Nevertheless, the Wrights themselves, judging from the trouble they had had with the centre of pressure movement and with certain unexplainable happenings on the lateral control, were at the end of these 1901 experiments considerably discouraged, as they were then beginning to appreciate how much there was to be done.

They saw that their experiments up to date, superficially successful as they had been, in real truth showed that they had no sound knowledge as to the lift, or the resistance or the centre of pressure movement of a curved plane, much less how such knowledge, if they had it, was to be applied to obtain a practical controllable aeroplane.

Fortunately, they were so deeply interested that they were unable to drop the subject and were sufficiently courageous to commit themselves to a lengthy programme of laboratory research on the characteristics of aerofoils.

This was the real starting point of their ultimate success.

In the 1916 Wilbur Wright lecture, Mr. Griffith Brewer has described something of the range and method of this experimental work.

During the years when I was in constant touch with the Wrights, we were more interested in the application of the results than in the method by which they had been obtained. To my regret I must confess that I did not pay to the details of this work the attention which I now realise was its due.

I saw parts of the 16in. channel apparatus lying about in corners and examined some of the little metal aerofoils tested. My recollection of these is that they were about 6in. by 2in., and that the method of measurement used was one of comparison against a variable area presented normally to the wind stream. The variable area consisted of a system of fingers of known dimensions which were arranged like a set of weights. A great deal of time and trouble was spent in getting the apparatus to function in a manner considered satisfactory, but once it was tuned up, tests were conducted with great rapidity, and as to accuracy we have the solid and undeniable fact that full scale design based on

this model work was entirely satisfactory and in accordance with expectation. I have been given by Wilbur or Orville hundreds of aerodynamic figures of all kinds—speeds, climbs and propeller revolutions, etc.—and have never known the estimated figure to have been more than 1 per cent. or 2 per cent. out from the measured result.

An immediate effect of the channel work was to be seen in the 1902 glider, whose plane had an aspect ratio of 6 and which had a fixed fin behind the planes. The gliding angle was found to be considerably better than the year before.

The first stage in the search for control had been the warping wings; the fixed fin of 1902 was the second stage and was the result of a study of the lift and drag figures obtained during the winter's work in the laboratory. From these figures they found an explanation for the occasional failures of the lateral control, when the lower wing continued to drop although its angle of incidence had been increased. What was of course happening was that the drag of that wing was increased and its speed decreased and that this loss of speed more than counteracted the increase of angle. By means of the affixed fin the Wrights expected to hold the wing up to its work and make the warp operate properly, and up to a certain point it did so.

The 1902 glider with the fixed fin undoubtedly was an improvement on the 1901 machine, but still it was not right and difficulties of control were occasionally experienced. When the machine side-slipped the fixed fin which was behind the wings tended to turn the machine about the vertical axis, speeding up the upper wing and slowing down the lower and so increasing the bank. This difficulty was eventually met by making the fin into an adjustable one, which could be turned to obtain the necessary pressure on the side towards the upper wing. It would appear probable that it was the actual movements of the aeroplane itself during the moments of instability which gave the clue to this, but it is hard to believe that the Wrights would have so quickly found a way through the bewildering tangle of these problems of control without the fundamental characteristics of an aerofoil to fall back upon.

When in the following year the first power machine was being designed they were able to go straight ahead without serious difficulty until they found themselves up against the design of the propeller. This proved to be a very serious obstacle and was not surmounted for several months.

The first power flights of December, 1903, were, apart from their great historical importance, really only a practical demonstration of the research work and technical development of the preceding three years.

During the next two years the experimental flying, apart from the mechanical troubles incidental to such work, was continually being held up by difficulties which could only be met by going back to the first principles and the characteristics of an aerofoil.

As an instance, they had trouble with instability on a turn which afterwards turned out to be due to stalling. The 1905 machine was flying with so small a margin of power that sometimes on a turn the angle of incidence of the lower wing tip would exceed the "critical angle" of lift and lateral control would be lost. As is well known serious accidents are still occurring from this cause.

It was eight or nine years before clear explanations of the phenomenon of the stalling of an aeroplane on the straight or on a turn were available. Certainly those who worked on the Public Safety and Accidents Committee in 1912 and 1914 will remember how inexplicable some of the accidents appeared to be, how widespread, even in 1913, was the lack of knowledge and understanding of this matter.

The first lesson to be learnt from the work of the Wright brothers is of the immense importance of fundamental research work in the laboratory.

Another very important lesson to be drawn is as to the value of the closest co-operation between laboratory and field work.

The first period was devoted to the study of all the available information and to thought about the essentials of the problem. Then came two periods of practical experiment in the field, the first short and the second of considerable length. This full-scale work gave the Wrights a good deal of experience and confidence in what they were doing, but above all made it clear to them that whether they liked it or not they had to go back again to the beginning and get down to the fundamental research, which was the only foundation on which a permanent structure could be built.

With data in their possession they returned to the application of it on the full scale with immediate success and from then on their progress was steady and continuous.

The reason why this research data obtained by the Wrights could not be given to the world was that their own financial situation and their obligations to the purchasers of their patents, in their opinion, compelled them to keep the data in their own possession.

It is not my wish to exaggerate the importance to the world's knowledge of aeronautical research, of the work of the Wright brothers, but it is my desire to lay the strongest emphasis on the lessons to be learnt therefrom, namely, that the whole basis of aeronautical progress rests upon genuine research in the laboratory, on the development of mathematical lines of attack and on full-scale research work in the field, and cannot possibly rest only or even mainly upon technical development.

Brilliant craftsmen and engineers though they were, it is certain that the Wrights would never have solved the problem of flight if they had not the fundamental data to guide them in times of difficulty.

Turning now to the immediate pre-war period, we find that aeronautical research in this country was put on a very solid foundation, and between the year 1909 and 1914 a very large amount of the necessary fundamental data was obtained at the National Physical Laboratory, at the Aircraft Factory, Farnborough, and by independent experimenters. Both the official establishments were generously subsidised and supported from national funds and all the necessary elaborate apparatus up to 7-foot wind channels were built, developed and worked at high pressure.

Before the outbreak of the war complete information was obtained and was available for designers as to the lift, drag and centre of pressure movement of a wide range of aerofoil sections, as well as for a large number of complete models.

Figures were available as to the actual pressures experienced over the upper and lower surfaces of the aerofoil.

The relations between model and full scale had reached a state of knowledge almost as far advanced as to-day.

Resistance of all exposed parts, such as bodies, struts, wires, wheels, etc., had been measured and were available for the designer. All the main problems of stability as regards the longitudinal movements had been investigated mathematically and experimentally and were considered to be satisfactorily solved. As regards the lateral and directional stability, the problems had been dealt with on mathematical lines and the lines of experimental investigation determined. The complete solutions to these problems have not yet been found.

The strength requirements and methods of stress calculation for an aeroplane had been settled and the load factors then decided upon are substantially the same to-day, although the increase in dimensions has introduced certain modifications. All the main facts as regards propeller design and manufacture were available.

Finally, practically all the vital features of this information had been checked by full-scale work and all the instruments really essential for the safety of the pilot had been designed and tested.

It is impossible at this date to read again the Advisory Committee reports up to the beginning of the war, as I have done in the preparation of this paper,

without being astonished at the wide range of the work and the accuracy of the deductions.

Research in the War Period.

It is frequently stated that aeronautical progress under the stimulus of war was rapid and continuous. This statement is only true to a limited degree. Progress in the art of flying itself, in the handling of aircraft by pilots was certainly both rapid and continuous, as also was the progress in methods of construction, materials and design from the engineering standpoint.

Great also was the progress in aircraft engines as regards the actual power, reliability, efficiency and reduction of weight. To this progress in engines is due almost entirely the tremendous increase in performance which was so marked a feature during the war.

In coming to a consideration of the progress in aerodynamics during this period, it is accurate to state that substantially there was none. Practically as much weight per horse-power could be carried in 1914 as in 1919 and as safely, and when one comes to think of it this was only to be expected, since during such urgent times efforts were concentrated on the technical development of what was known to be on sound lines rather than on researches, which were of necessity to some extent vague and indefinite and possibly of no immediate practical utility.

Research in the Post-War Period.

Since the war, money and the national effort as distinct from the individual effort put into research have steadily dwindled until it is safe to say that it is now far below the pre-war standard, when we had as well as the establishment supported by State fund, a large amount of work being done by private firms and individuals.

At the present date the few, extremely few, private firms who are left are so hard pressed to keep on their feet at all that they find it impossible to continue to devote their resources to anything outside the fulfilment of their definite orders.

As for private individuals they are, to the best of my knowledge, completely extinguished by the heavy hand of fate.

One of the most unfortunate results of the concentration during the war of all aeronautical matters into the hands of the State is that individual effort is now almost paralysed, and it is impossible for any one man, however broad-minded and far-sighted, to sympathise with all the wide aspects of aircraft research, particularly when continually harassed by orders to cut down his expenditure by so much per cent. as if he were a commercial traveller buying fire-irons.

To all persons interested in sound aeronautical development it is only too evident that the importance of fundamental research to real progress in aircraft design is not grasped by those in authority in this country. Even the word research itself is very imperfectly understood.

The initial problems are solved and technical development has gone far during the last ten years, but if the flying machine is to be of real benefit to the world in peace and to be a real means of rapid communication and of increase of friendliness among peoples, then big advances are necessary. Such advances are only to be obtained by laborious and systematic researches into the problems we can see dimly as well as those we can see more clearly immediately in front of us.

The immediate problems are those directed towards the improvement of the present type of aeroplane so as to increase its safety of operation. The main obvious defects are, that its minimum flying speed is too great and that the stability and controllability round about this speed are insufficient.

It is foolish to put the responsibility for accidents on the engine and to say that all that is necessary is so to improve the reliability of engine and installation that breakdowns cannot occur. Certainly the majority of interruptions are trace-

able to some breakdown in the power plant in which greater experience and care will undoubtedly make big improvements; but it can never be the case that mechanical breakdowns are absolutely impossible and it is essential that emergency landings can be accomplished without danger to the passengers or without even anxiety to the pilot. This is far from being the case at the present time and it is a mistake to attempt to conceal it.

To the immediate future of civil aeronautics the importance of safety is paramount and supreme over all other considerations, and the efforts which are now being made in the laboratory and on full scale to improve stability and controllability round about stalling speed are all to the good. The other main problem, namely, that of decreasing the dangers at the landing itself, cannot be attacked in an adequate manner until funds are available. This problem has two branches, one a decrease in the minimum flying speed while keeping the top speed about the same, and the other, an increase in the strength and efficiency of the landing mechanism itself. These are the immediate needs of the aeroplane itself, apart from the power plant. To go into the improvements which are immediately necessary in the latter would be really outside the scope of this paper, and in my opinion the main defects are at the moment in the aeroplane rather than in the engine.

Further off we can see the big advances which will be possible when we have a real understanding of the action of an aerofoil in the air, and how and why the air flows round it and gives it lift and drag. A brilliant experiment may show, and indeed has shown, that we are on the outskirts of knowledge, but before we can attain the citadel we must give encouragement and adequate support to the men who are devoting themselves to fundamental research of this character.

It is conceivable that lines of advance may then reveal themselves which would make it worth while to attempt even the design of a helicopter, but let us recognise that the present time is one requiring research work into the fundamental problems which must be solved before the world at large can reap the benefits of the wonderful achievement of Wilbur Wright and his brother.

TABLE A.
WRIGHT AEROPLANES 1910.

	Standard Machine.	Racing Machine.
Span	39ft.	20ft. 6in.
Chord	6ft. 3in.	3ft. 6in.
Gap	5ft. 6in.	3ft. 6in.
Area—main planes	475 sq. ft.	150 sq. ft.
Engine	35 h.p. (4-cyl.)	60 h.p. (8-cyl.)
Total weight	1,320lbs.	900lbs.
Loading per h.p.	37.5lbs.	15lbs.
Loading per sq. ft.	2.75lbs.	6lbs.
Speed	38 m.p.h.	75 m.p.h.
Weight Details.		
Structure	475lbs = 36%	250lbs. = 28%
Engine rad. and water	285 } 12lbs. per	361 } 7½lbs. per
*Propellers, chains, etc.	132 } h.p.	87 } h.p.
Fuel and tank	84 (10 gal.)	74 (9 gal.)
Crew	344 (2)	128 (1)
Total	1,320lbs.	900lbs.

* Same type of propeller was used for both machines.

TABLE B.
DATA AS TO GLIDERS.

Year.	Span.	Chord.	Area.	Empty	Loaded	Angle of Glide.	Loading lbs. per sq. ft.
				Weight.			
1900	18ft.	5ft.	165 sq. ft.	50lbs.	190lbs.	8° to 9°	1.15
1901	22ft.	7ft.	308 „	100lbs.	240lbs.	7° to 8°	.78
1902	52ft.	5ft.	305 „	120lbs.	260lbs.	6° to 7°	.82
1911	32ft.	5ft.	305 „	145lbs.	310lbs.	6°	1.00



HELICOPTERS.

BY JOHN CASE, M.A., F.R.A.E.S.

Summary.

The present article is an account of some calculations on helicopters.

Airscrews have been calculated for different conditions according to two theories: (1) the multiplane interference theory; (2) Glauert's vortex theory. According to both there should be no difficulty in designing a screw to give a good lift at a reasonable rate of climb, and the ceiling should also be quite good. When we consider the speed of falling, with the screws free-wheeling, the two theories give widely different results, and the practicability of the helicopter depends largely upon this question being settled. Simple airscrew theory shows that at least moderate speeds should be obtainable by inclining the airscrew axis. For many reasons it seems desirable that the screws should have at least four blades; gyroscopic couples on the whole machine are eliminated; the forces are widely fluctuating during forward motion with only two blades; the stability derivatives and equations are simplified; but the aerodynamic efficiency will be impaired. In general the stability equation is of the tenth degree, and the lateral and longitudinal stabilities are not separable when the machine, in a state of steady motion in a straight line, receives an asymmetrical disturbance.

The following notes are the results of an attempt to investigate the theoretical possibilities of the helicopter, and generally to develop some branches of the theory of helicopters. In this country extremely little work on the subject seems to have been published, and the only experiments I have been able to find are those given in the Report of the Advisory Committee for 1917-18 (Vol. II.). Several articles have appeared in "*L'Aérophile*" from time to time, notably by Lamé, Touissaint and Margoulis, and some experimental work has been done by Eiffel. But it is extremely difficult to find adequate experimental results with which to compare any theory; for instance it is very rare to find results of tests on airscrews working under helicopteral conditions, and also the aerodynamic data of the aerofoil sections used. In the matter of stability I do not know of any experimental work at all.

I shall give first the results of my investigations into airscrews for helicopters, and then proceed to the consideration of the dynamics of helicopter flight and the development of the stability equations.

1. Airscrews for Helicopters.

In setting out to calculate the characteristics of the supporting screws of a helicopter we must consider what method to employ, for evidently the simple blade-element theory, without corrections, cannot be expected to give reliable results when the airscrew is at rest axially. The two most modern theories of the airscrew are the multiplane interference method developed by R. McKinnon Wood,* and the vortex theory given by H. Glauert.† Both these methods seem to give good results when applied to tests on the type of airscrews used for aeroplanes. In using the multiplane interference method we may estimate the corrections from the experimental data given in R. and M. 639, or calculate them by the vortex theory of aerofoils as suggested by H. Glauert.‡ For the helicopter we must be able to calculate the properties of an airscrew when working under the condition of no advance in the direction of the axis, and the first step I have taken is to compare calculated and experimental results. Unfortunately very little can be done in this direction.

* See R. & M. 639.

† See R. & M. 786.

‡ See R. & M. 752.

Taking first the helicopter screws described in the A.R.C. Report for 1917-18, no direct experimental data exist for the properties of the cross sections of the blades and the best we can do is to plot probable lift and drag curves for the sections according to their camber. This refers only to the blades having a flat under-surface.

In the propeller considered the pitch angle is constant along the blade. First the thrust was calculated with the blades set at 2 deg. to the plane of rotation, the corrections being estimated from the experimental data given in R. and M. 639. It was found that a screw 40ft. dia. running at 275 r.p.m. should give a thrust of 2,000 pounds per blade; according to the test on the complete model airscrew the thrust should be 400lbs. per blade. Next the screw was calculated under the same conditions, by the same method, except that the corrections were calculated by the vortex theory of aerofoils; this led to a thrust of 370lbs. per blade. With the blades set at 6 deg. and running at 144 r.p.m. the same process gave a thrust of 425lbs. per blade, the value deduced from the model test being 400lbs. in each case. Thus the agreement between the calculated and experimental results was fairly good when the multiplane effect was calculated by the vortex theory.

The next example chosen for calculation was the propeller used by the N.P.L. for pressure distribution experiments and described in R. and M. 681. It is not possible to check the multiplane interference method for no advance with this screw, as the angles are too large, but I have used it to check the vortex theory of airscrews. Fortunately, for this screw we have tests on the sections to which the blades were cut. At 15 r.p.s. the calculated thrust is 14.4lbs. on the model, and the observed thrust was 13.2lbs.; the calculated torque is 3.08lbs. ft., and the observed torque was 3.25lbs. ft.

From these figures it appears that we might expect to obtain reasonable results for airscrews working under helicopteral conditions either by Glauert's vortex theory of airscrews, or by the multiplane interference method, provided we calculate the corrections by the vortex theory of aerofoils. At the same time it must be remembered that the experimental evidence is very slight. Of the two methods the vortex theory of airscrews is the more purely logical, and involves no empiricism, while the question of aspect ratio must always make the multiplane method rather doubtful. When I started on this work I was not aware of Glauert's paper, and worked entirely with the multiplane method, calculating the corrections by the vortex aerofoil theory. Since then I have done most of the calculations again by his method, and there is considerable difference between the results. For helicopter screws hovering or climbing, Glauert's theory gives more hopeful results than McKinnon Wood's multiplane method. but the converse is the case when we deal with a helicopter falling with the screws free to rotate as windmills.

2. H. Glauert's Airscrew Theory.

As far as concerns airscrews used on aeroplanes, this is fully set out in R. and M. 786, and will not be described here, except to say that it differs very little from the common inflow theory in method, and that the fundamental principles of it are that the theoretical inflow factor $\frac{1}{2}$ is used, and the aerofoil characteristics employed are those of the monoplane of infinite aspect ratio. These are obtained from the characteristics of the finite monoplane by the method set out in R. and M. 723.

The manner of dealing with the case of $V=0$, and the case of the helicopter descending with blades reversed is not contained in R. and M. 786, but has been given to me since by Mr. Glauert, and is given here.

§ These figures were found by calculating for small values of V/nD and extrapolating, as the method breaks down when V is zero.

3. Helicopter Screw Hovering.

The following notation is used:—

N = number of blades.

D = diameter of screw = $2R$.

B = blade width at radius r .

k_L = lift coefficient for aerofoil, of infinite aspect ratio, of the same section as the airscrew blade at radius r .

k_D = drag coefficient of ditto.

θ = pitch angle of section.

α = angle of incidence.

$\gamma = \tan^{-1} (k_D/k_L)$.

$\Omega = 2\pi n$ = speed of rotation (radians per second).

$a''r\Omega$ = axial velocity of air through the propeller disc at radius r .

$a'\Omega$ = rotational velocity of the air in passing through the propeller disc.

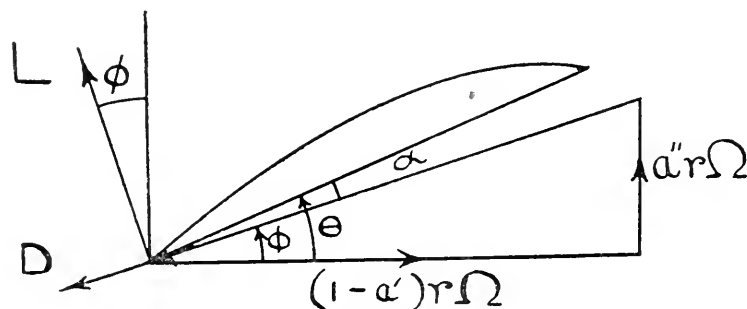


FIG. 1.

Then it can be shown that

$$\phi = \theta - \alpha \quad (1)$$

$$\tan \phi = a''/(1 - a') \quad (2)$$

$$a' \tan^2 \phi = a'' F'' \tan (\phi + \gamma) \quad (3)$$

$$a''^2 (1 - F'' \cot^2 \phi) - 2\delta' a'^2 = 0 \quad (4)$$

where

$$F'' = \{ k_L \cos (\phi + \gamma) \} / (S \cos \gamma \sin^2 \phi) \quad (5)$$

$$S = 4 \pi r / NB \quad (6)$$

and δ' is the quantity referred to in R. and M. 786, and may be taken as zero without serious error. Taking arbitrary values of α , θ is given, and so ϕ is obtained from (1); F'' is then calculated from (5) and (6), whilst (2) and (3) give a' and a'' . All the quantities are now found, and it remains that equation (4) must be satisfied; by plotting the left-hand side against α we find the value of α which makes this zero. All the equations are then satisfied.

The thrust (dT) and torque (dQ) of the element are given by

$$dT = 4 \pi r^3 \rho \Omega^2 (1 - a')^2 F'' dr \quad (7)$$

$$dQ = r \tan (\phi + \gamma) dT \quad (8)$$

If we write, as is usual,

$$T = \rho n^2 D^4 k_T$$

$$Q = \rho n^2 D^5 k_Q$$

we have

$$k_T = 2 \pi^3 \int_0^1 (1 - a')^2 F'' x^3 dx \quad (9)$$

$$k_Q = \pi^3 \int_0^1 (1 - a')^2 F'' \tan (\phi + \gamma) x^4 dx \quad (10)$$

where

$$x = r/R = 2r/D.$$

Thus, when plotting the left-hand side of equation (4) against α , it is advisable to plot $(1 - a')^2 F''$ so that the value of this quantity when equation (4) is satisfied is easily found. This is repeated for each cross section of the blade, and k_T and k_Q are then obtained by integration along the blade.

4. Descent with Screws Free.

If a helicopter is to descend safely in the event of engine failure, it must be possible to disengage the screws from the engines and to reverse the blades to prevent stoppage followed by rotation in the opposite direction. This case is calculated as follows:—Neglecting inflow the conditions which obtain at a blade

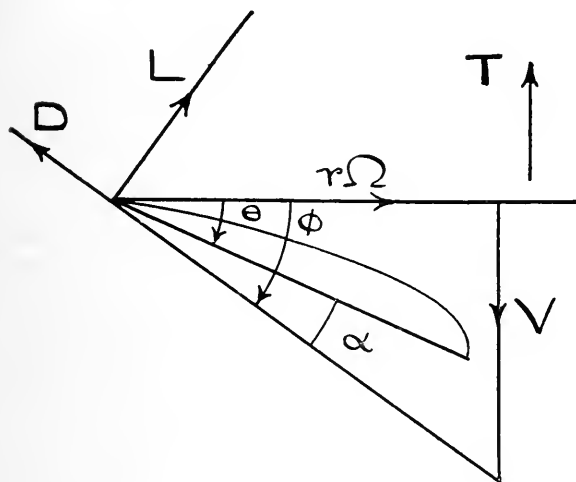


FIG. 2.

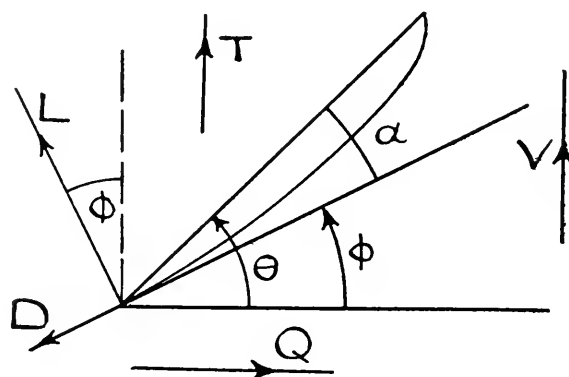


FIG. 3.

element are as shown in Fig. 2. If we still consider θ and ϕ positive, α will be negative, in the case shown, and k_L will be positive; if α be positive (*i.e.*, $\phi < \theta$) and numerically greater than the no-lift angle, k_L will be negative. Evidently we can bring this case into line with the standard case as shown in Fig. 3, *i.e.*, if we change the signs of both α and k_L in the aerofoil characteristics. Then a negative value of T and a positive value of V correspond with the helicopter falling against an upward thrust, and a negative value of Q corresponds with a braking couple applied to the shaft.

The notation is the same as in the previous case, with the following additions or modifications:—

V = axial velocity of screw

aV = increase of relative velocity of air in passing through the propeller disc.

$$F = \{ k_L \cos(\phi + \gamma) \} / \{ S \cos \gamma \sin^2 \phi \} \quad (11)$$

and it should be noted that, when k_D/k_L is numerically small, γ is in the neighbourhood of 180° not 0° .

Taking arbitrary values of α , F is calculated from (11), and then

$$J = V/nD = \pi x \tan \phi_0 \quad (12)$$

where

$$\tan \phi_0 = \{ (1 - F) \tan \phi \} / \{ 1 + F \tan \phi \tan(\phi + \gamma) \} \quad (13)$$

We also have

$$dk_T/dx = J^2 \pi x F / (1 - F)^2 \quad (14)$$

$$dk_Q/dx = - (dk_T/dx) (x/2) \tan(\phi + \gamma) \quad (15)$$

where, as before, $x = r/R$.

Thus we can plot dk_T/dx and dk_Q/dx against J for each section of the blade, and hence plot them along the blade for a given value of J , and, by integration, find k_T and k_Q . Finally we can plot k_Q and k_T against J . If there is no applied

couple k_Q must be zero. This gives the value of J at which the helicopter will fall. Neglecting other resistances we must have

$$T = \rho n^2 D^4 k_T = W$$

where W is the weight supported. Hence both n and V are determined.

5. Numerical Investigation.

In investigating the properties of airscrews for helicopters I have used the blade shown in Fig. 4.

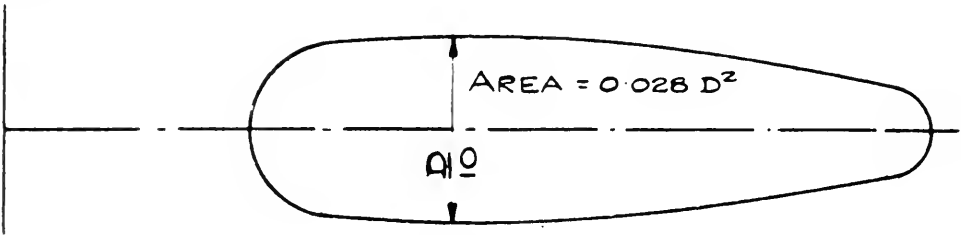


FIG. 4.

The sections are series B in R. and M. 362, and the numbers used here to denote the sections are the same as in R. and M. 362. For the rest, the blade shape is defined as follows :—

Section	...	...	A	B	C	D	E	F
Aerofoil number	...	...	7	6	5	4	3	2
Camber	...	...	0.2	0.16	0.12	0.10	0.09	0.08
r/R	...	...	0.34	0.48	0.66	0.76	0.83	0.95
B/B_0	...	...	0.91	1.00	0.935	0.82	0.73	0.48

where B is the blade width at any section, and B_0 is the maximum blade width. The characteristics of the sections for infinite aspect ratio are shown in Fig. 5.

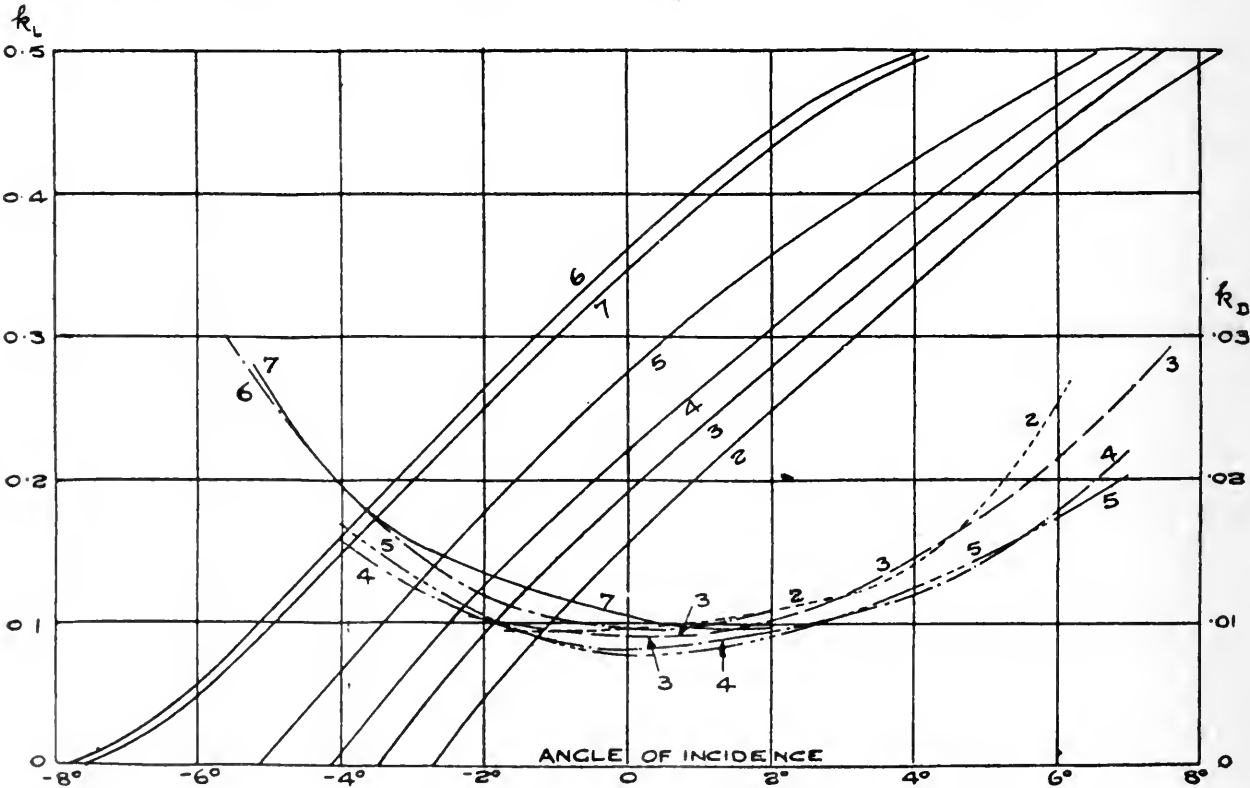


FIG. 5.

6. Helicopter Hovering.

The first calculations were made to determine the probably best ratio of pitch to diameter to obtain the greatest lift per horse-power when the machine is

stationary in the air, and to see what lift may be expected under these conditions. The results are given in Fig. 6, and Table I.

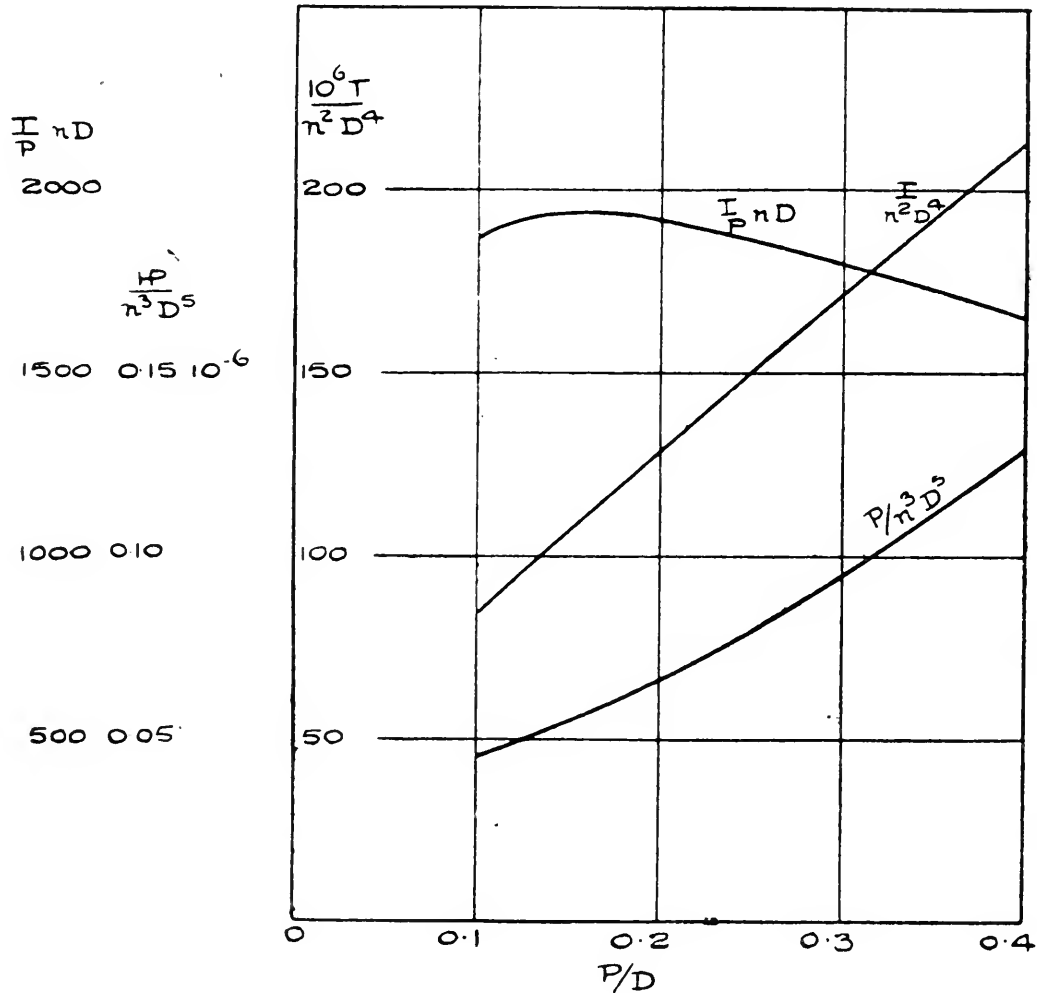


FIG. 6.

TABLE I.

HELICOPTER SCREW HOVERING—TWO-BLADE AIRSCREW.

Pitch/Dia.	0.1	0.2	0.3	0.4
$T/n D^4$...	85.3	128	170	213.10^{-6}
$Q/n^2 D^5$...	4.0	5.89	8.30	$11.3.10^{-6}$
$P/n^3 D^5$...	0.0456	0.0672	0.0948	$0.129.10^{-6}$
$nD T/P$...	1870	1910	1790	1650

T =thrust (lbs.), Q =torque (lbs. ft.), P =horse-power at standard density; n =revs. per sec., D = dia (ft.).

It appears from this that the best pitch-dia. ratio for hovering will be about 0.2. As an example of the meaning of these figures it will be seen that a two-blade screw 40ft. dia. running at 60 r.p.m. would give a total lift of about 330lbs., at the rate of 48lbs. per horse-power. There is evidently no difficulty, according to these figures, in designing a helicopter to support itself in still air.

7. Helicopter Climbing.

The thrust per horse-power obtainable from a helicopter screw which is at rest axially is obviously no criterion of the feasibility of the helicopter, for the thrust will certainly be less when the machine is climbing. To ascertain the effect of the rate of climb I have taken a screw as described above, with a pitch/dia. ratio of 0.3, and having two blades. The general results of the calculations are given in Table II. and Fig. 7.

TABLE II.
HELICOPTER SCREW CLIMBING. PITCH/DIA.=0.3.

V/nD	0	0.20	0.25	0.30	0.35	
k_T	0.0716	0.051	0.0434	0.0346	0.026	
k_Q	0.0035	0.00338	0.0032	0.0030	0.00278	
$T.10^6/n^2 D^4$	170	121	103	82	61.5	Calculated by vortex theory of airscrews.
$Q.10^6/n^2 D^5$	8.3	8.0	7.6	7.1	6.6	
$P.10^6/n^3 D^5$	0.0948	0.0913	0.0867	0.081	0.0754	
$nD T/P$	1800	1330	1190	1010	815	
$T.10^6/n^2 D^4$		82.4	66	50	36	Calculated by multiplane theory with calculated cor- rections.
$P.10^6/n^3 D^5$		0.0774	0.074	0.070	0.065	
$nD T/P$		1070	870	720	590	

For comparison the results of the two methods of calculation are given, and it will be seen there is considerable difference between them. In Fig. 7 only the results found by the vortex airscrew theory are shown.

Now let us suppose it is required to carry a nett weight of 1,000lbs., exclusive of the airscrew surfaces, and let us take the weight of these as 1.75lbs. per square foot, and let the rate of climb at ground level be 350ft. per minute. We consider the question of the number of propellers used, and obtain the following results:—

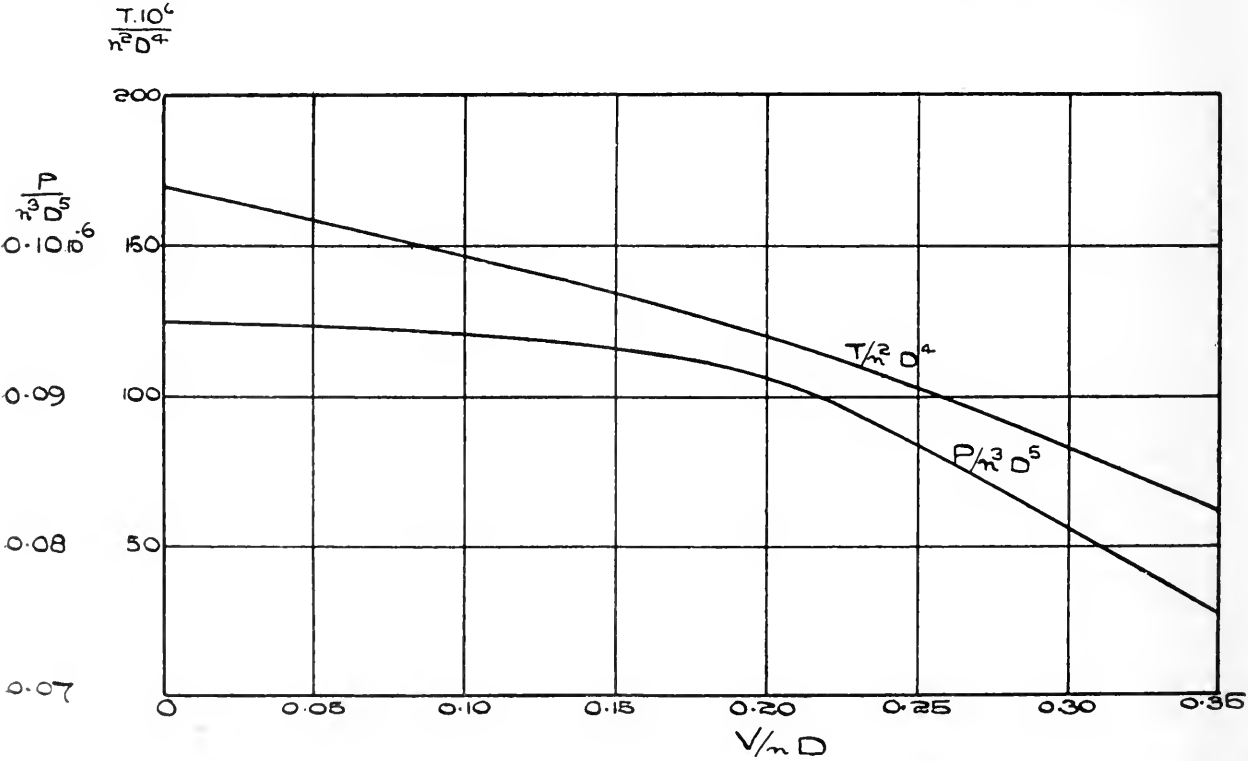


FIG. 7.

TABLE III.

Diameter 25ft., two blades.

Number of screws	...	...	2	4	6
Revs. per sec.	...	...	3.08	2.34	2.04
Nett lift per h.p.	...	...	18.5	21.7	20.9
Total lift per h.p.	...	...	20.7	27.0	28.4

Diameter 40ft.

Revs. per sec.	...	...	1.32	1.06	0.97
Nett lift per h.p.	...	...	22.2	20.8	17.6
Total lift per h.p.	...	...	29.4	33.7	33.8

These figures were obtained by the vortex airscrew theory, and are extremely hopeful. The figures found by the multiplane theory are not quite so good, but are still very promising, thus with two screws 40ft. dia. a nett lift of 14.3lbs. per h.p. is given, and this method of calculation does not show so much difference between the results of using two, four, or six propellers. The figures shown in Table III. show a great advantage in using several screws, but this might easily be cancelled by the extra complication and weight of gearing necessary, and it must also be remembered that these calculations take no account of the interference between the screws, which will be almost inevitable.

8. Next let us consider the effect of rate of climb on the power required. Again, suppose the weight to be lifted is 1,000lbs. exclusive of the lifting surfaces, and that these weigh 1.75lbs. per sq. ft. Let us use two 2-blade screws, each 40ft. dia., with a pitch/dia. ratio of 0.3. The power required for different rates of climb at ground level is shown in Fig. 8, on the assumption of given total weight (in this case about 1,310lbs. with the airscrews).

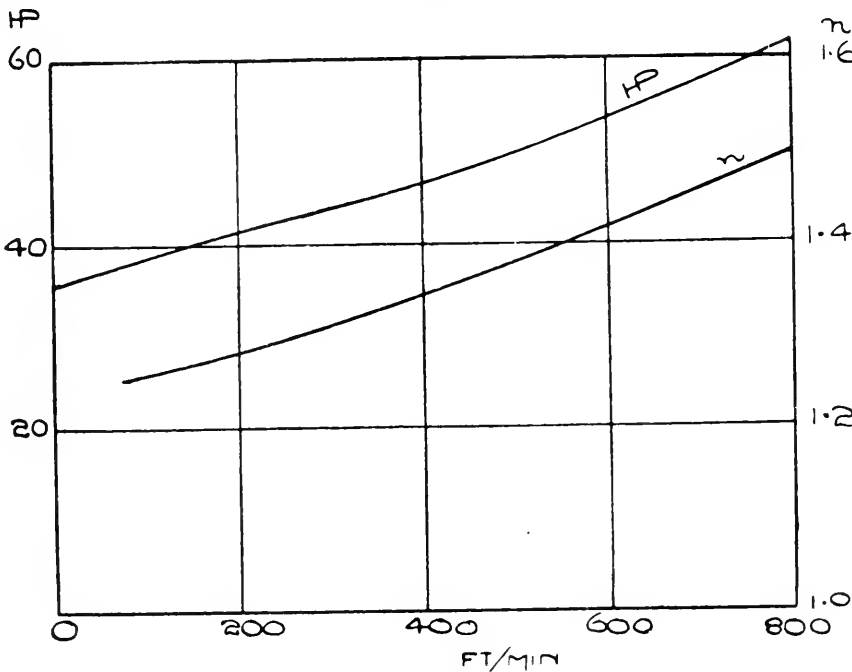


FIG. 8.

Now suppose our machine fitted with an engine which will give a maximum propeller horse-power of 60 at ground level, at 90 r.p.m., and examine what will be the ceiling. Such an engine will give a climb of 740ft. per minute at ground level. The speed of rotation necessary to hold the machine in the air will be proportional to $\sigma^{\frac{1}{2}}$, and the power required will vary as $\sigma^{\frac{3}{2}}$, where σ is the relative density. If we use the height factor for engine horse-power given by Bairstow,* and assume the engine power at a given height to be proportional to

* "Applied Aerodynamics," Fig. 205b.

the speed, we find that the ceiling will be about 8,000ft. If a supercharger be fitted the ceiling will be 14,000ft. if 90 r.p.m. represents the maximum permissible speed of the engine. If the engine can run up to a propeller speed of 100 r.p.m., the ceiling will be increased to about 20,000ft.

9. Descent with the Screws Free.

I shall suppose here that the screws are designed to get the best results under this condition, regardless of their efficiency for climbing purposes. The method of calculation has been described above.

Taking first a pitch/dia. ratio of 0.3, it will be found that, according to the vortex theory, Q is zero when $V/nD=0.32$, and that then the thrust coefficient k_T is 0.03, so that, at standard density $T=690 V^2 D^2 10^{-6}$ lbs., and the value found by the multiplane theory is not very different. When the pitch/dia. ratio is reduced to 0.2 the thrust when the torque is zero is increased, slightly, to $720 V^2 D^2 10^{-6}$. If the pitch is reduced to $0.1 D$ the airflow appears to be very uncertain and it is difficult to interpret the theoretical figures found by the vortex method. An improvement is effected by using a blade in which all the sections are aerofoil section 7 (see above); with a pitch equal to $0.3 D$, we find $T=810 V^2 D^2 10^{-6}$. With this value for T , a screw 40ft. dia. would exert a braking force of 500lbs. when falling at 20ft. per sec. In this type of screw the airflow seems to become uncertain when the pitch is reduced to $0.2 D$. The thrust exerted by two-blade screws of this type, with a pitch $=0.3 D$, falling at various speeds, is shown in Fig. 9.

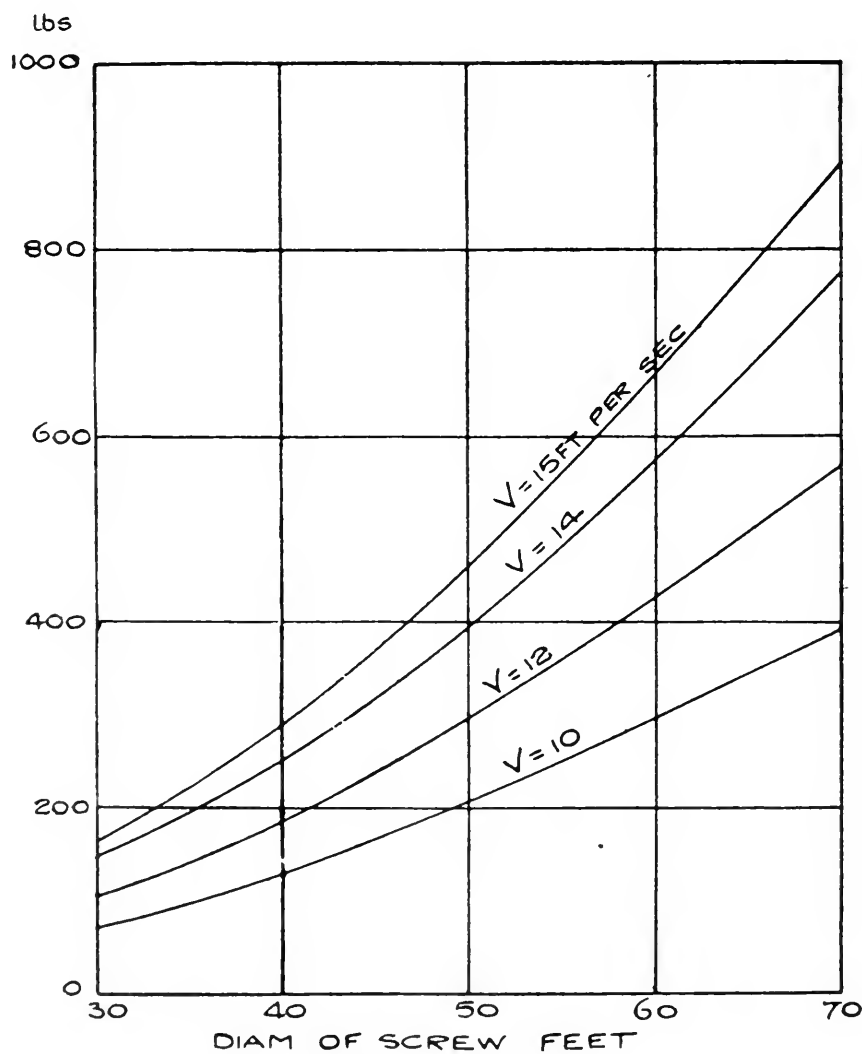


FIG. 9.

From this it will be seen that it would take six such screws, each 60ft. dia., to support a weight of 1,200lbs. exclusive of their own weight, when falling at 12ft. per sec., if each screw weighs 225lbs.

The figures obtained by the multiplane method, calculating the interference effect by the vortex theory of aerofoils, promise a much more easy solution of the problem of safe descent with the screws free, for according to this method of calculation six propellers 40ft. dia. would support 2,800lbs. exclusive of themselves, when falling at 13.5ft. per sec. The results of the two methods of calculation are summarised in Table IV. and Fig. 10.

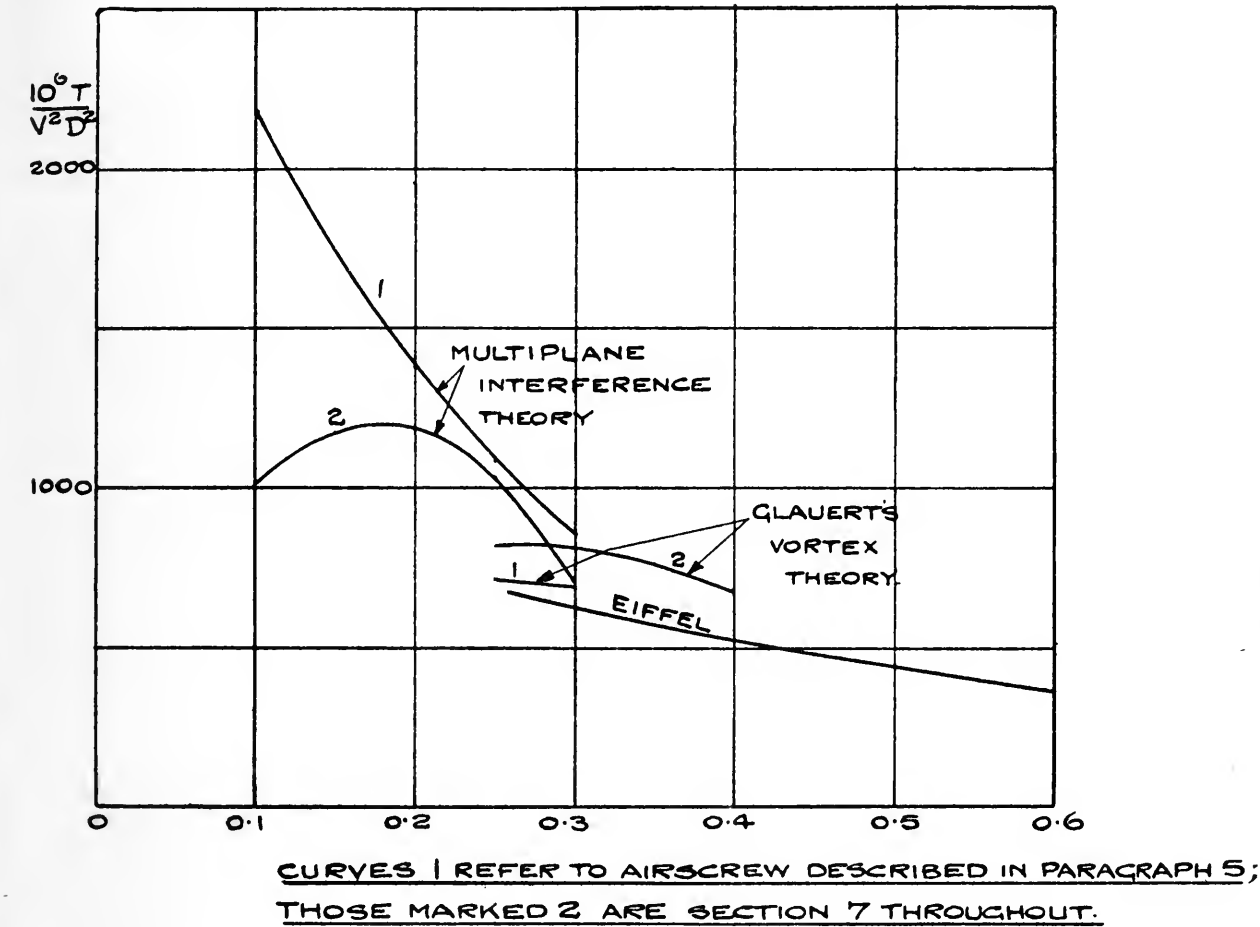


FIG. 10.

TABLE IV.

Standard Blade as above.				All Blade Sections are No. 7.				
Pitch/Dia.	0.1	0.2	0.3	0.1	0.2	0.25	0.3	0.4
V/nD	0.2	0.265	0.30	0.27	0.31			
$10^6 T/n^2 D^4$	79.2	85	63.6	159	138			
$16^6 T V^2/D^2$	990	1210	710	2180	1432			
V/nD	—	0.365	0.32	—	0.42	0.375	0.37	
$10^6 T/n^2 D^4$	—	95	71.1	—	144	113	93.5	
$10^6 T/V^2 D^2$	—	720	690	—	815	810	685	

The table shows the values of the various quantities when $Q=0$; the first set of figures was obtained by the multiplane method, the lower set by the vortex aircrew theory.

Taking the best results of each, the multiplane theory gives a lift of more than $2\frac{1}{2}$ times that given by the vortex theory for the same speed of falling.

It is worth noting perhaps that the drag of a fixed airscrew of this shape, of R.A.F.6 section, would be $93 V^2 D^2 10^{-6}$.

10. Forward Motion by Inclination of Screw Axis.

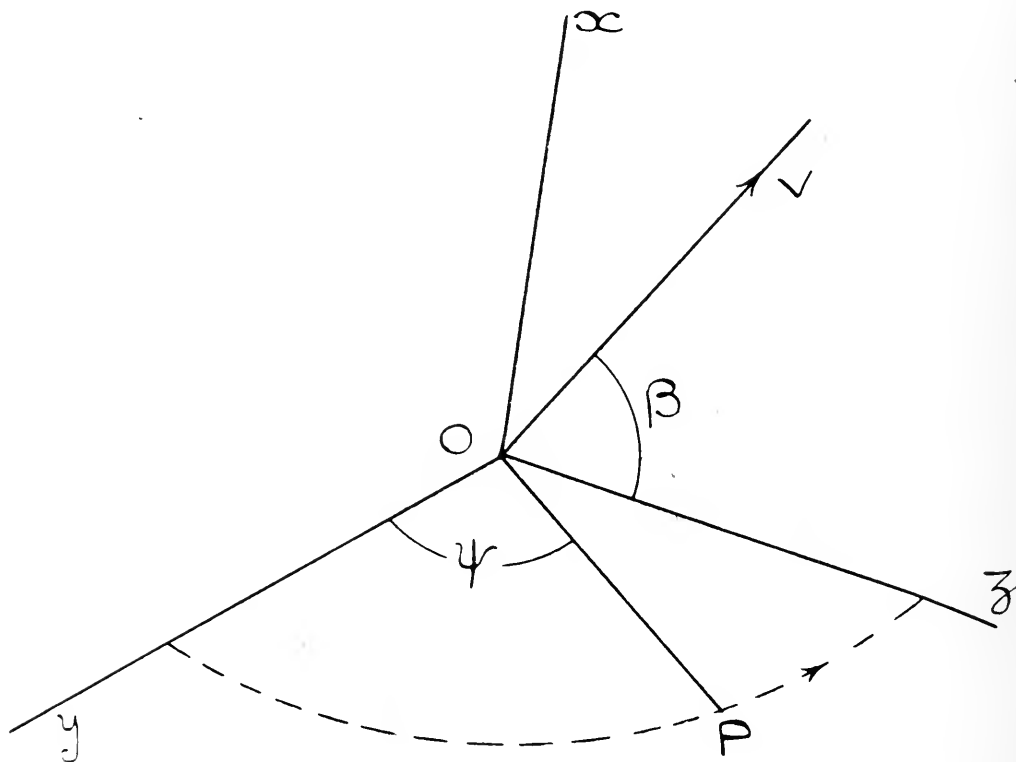


FIG. 11.

Referring to Fig. 11, let the axis of x be directed along the airscrew axis, and let the axis of y be at right-angles to the plane containing Ox and the direction of motion of the centre of the screw; Oz is at right-angles to Ox and Oy .

Let V be the velocity along the flight path.

β = the angle VOz .

The component velocities of the blade element P are

$V \sin \beta$ along Ox .

$V \cos \beta \cos \psi + \Omega r$ at right-angles to OP and Ox .

$V \cos \beta \sin \psi$ along OP .

We neglect the effect of the last of these.

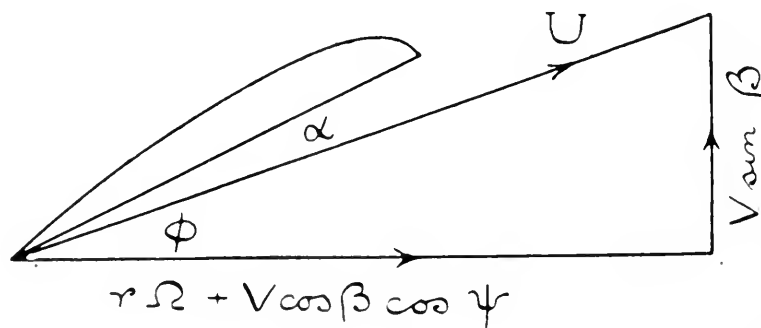


FIG. 12.

Let U be the resultant velocity of the wind relative to the blade element, and making an angle ϕ with the plane of motion.

Let X, Y, Z be the total force on the blade in the position ψ .

Let Q be the corresponding torque.

Let $\bar{X}, \bar{Y}, \bar{Z}, \bar{Q}$ be the mean value of these quantities taken round a whole revolution.

Then, with the simple blade-element theory, we have

$$\begin{aligned} X &= \rho B_0 D^3 n^2 \int_0^1 B/B_0 (U/nD)^2 (k_L \cos \phi - k_D \sin \phi) d\xi. \\ Y &= \rho B_0 D^3 n^2 \int_0^1 B/B_0 (U/nD)^2 (k_L \sin \phi + k_D \cos \phi) \sin \psi d\xi. \\ Z &= \rho B_0 D^3 n^2 \int_0^1 B/B_0 (U/nD)^2 (k_L \sin \phi + k_D \cos \phi) \cos \psi d\xi. \\ Q &= \frac{1}{2} \rho B_0 D^4 n^2 \int_0^1 B/B_0 (U/nD)^2 (k_L \sin \phi + k_D \cos \phi) \xi d\xi. \end{aligned}$$

and

$$\bar{X} = \frac{1}{2\pi} \int_{2\pi}^0 X d\psi \quad \bar{Y} = \frac{1}{2\pi} \int_0^{2\pi} Y d\psi \quad \bar{Z} = \frac{1}{2\pi} \int_0^{2\pi} Z d\psi \quad \bar{Q} = \frac{1}{2\pi} \int_0^{2\pi} Q d\psi$$

where

$$\xi = r/R = 2r/D$$

$$B = \text{blade width at radius } r$$

$$B_0 = \text{maximum blade width}$$

$$U^2 = (2\pi r n + V \cos \beta \cos \psi)^2 + V^2 \sin^2 \beta$$

$$\tan \phi = \{ (V/nD) \sin \beta \} / \{ (V/nD) \cos \beta \cos \psi + \pi \xi \}$$

It would seem that this is the only calculation we can do at present for an airscrew working under these conditions, for all our vortex theories presuppose small angles of incidence, whereas in the case we shall examine presently the angle of incidence varies from $+9^\circ$ to -144° .

11. Before making a numerical analysis of a screw let us investigate the magnitudes of the various quantities. We shall write

$$T = \rho n^2 D^4 k_T$$

$$Z = \rho n^2 D^5 k_Z$$

Experiments made on a propeller with its axis at right angles to the wind ("Aeronautical Research Committee," 1916-17, Vol. I., p. 293) show that the thrust is very little affected by the side wind up to the greatest value of V/nD (2.2) used in the experiments.

Also we can write,* when β is 90° ,

$$k_T = k_{T0} - b (V/n)^2$$

where

$$k_{T0} = 4/3 K$$

and

$$b = 1/K P_m^2$$

* See R. & M. 474 or 577.

K being a constant of the screw such that $Kk_T = 1$ when $V/nP_m = \frac{1}{2}$. In view of the experiments just cited we shall suppose that this holds for the inclined screw if we write $V \sin \beta$ for V . We then have

$$T = \rho n^2 D^4 \{ k_{T0} - b (V/n)^2 \sin^2 \beta \} \\ = T_0 - \rho b V^2 D^4 \sin^2 \beta.$$

T_0 being the value of T when β is zero.

The propulsive force in the direction of motion is

$$T \sin \alpha = (T_0 - \rho b V^2 D^4 \sin^2 \beta) \sin \beta.$$

This is a maximum when

$$T_0 - 3\rho b V^2 D^4 \sin^2 \beta = 0$$

which gives

$$\sin \beta = \sqrt{(T_0 / 3\rho b V^2 D^4)} = \sqrt{(Kk_{T0} n^2 P_m^2) / 3 V^2}$$

i.e.,

$$\sin \beta = (2/3) (nP_m / V)$$

Now consider the screw whose characteristics are shown in Fig. 7. The thrust is zero when $V/nD = 0.5$ about. Suppose $D = 40$, then $P_m = 20$. If $n = 1.5$ and $V = 150$ we find $\sin \alpha = 0.13$, or $\alpha =$ about 8° .

12. Let us then take for an example

$$\begin{aligned} \text{Pitch} &= 0.3D \\ V/nD &= 2.0 \\ \beta &= 10^\circ \end{aligned}$$

The only aerofoil section of which we have knowledge for all angles of incidence is R.A.F. 6. We find, if $B_0 = 0.1 D$.

$$\left. \begin{aligned} \bar{X} &= 84.10 - {}^6n^2 D^4 \\ \bar{Z} &= 13.10 - {}^6n^2 D^4 \\ \bar{Q} &= 4.6.10 - {}^6n^2 D^5 \end{aligned} \right\} \text{per blade}$$

at standard density.

The lift is

$$L = \bar{X} \cos \alpha + \bar{Z} \sin \alpha = 84.8.10 - {}^6n^2 D^4$$

The drag is

$$D = \bar{Z} \cos \alpha = 12.8.10 - {}^6n^2 D^4$$

The propulsive force is

$$F = \bar{X} \sin \alpha = 14.6.10 - {}^6n^2 D^4$$

Thus the nett propulsive force is $1.8.10 - {}^6n^2 D^4$. If $D = 40$ and $n = 1.46$, this only amounts to 7lbs. per blade.

No improvement is obtained by increasing the pitch to $0.4D$. Better results, however, are obtained by making $\alpha = 5^\circ$ all along the blade when $\psi = 0$. We then find

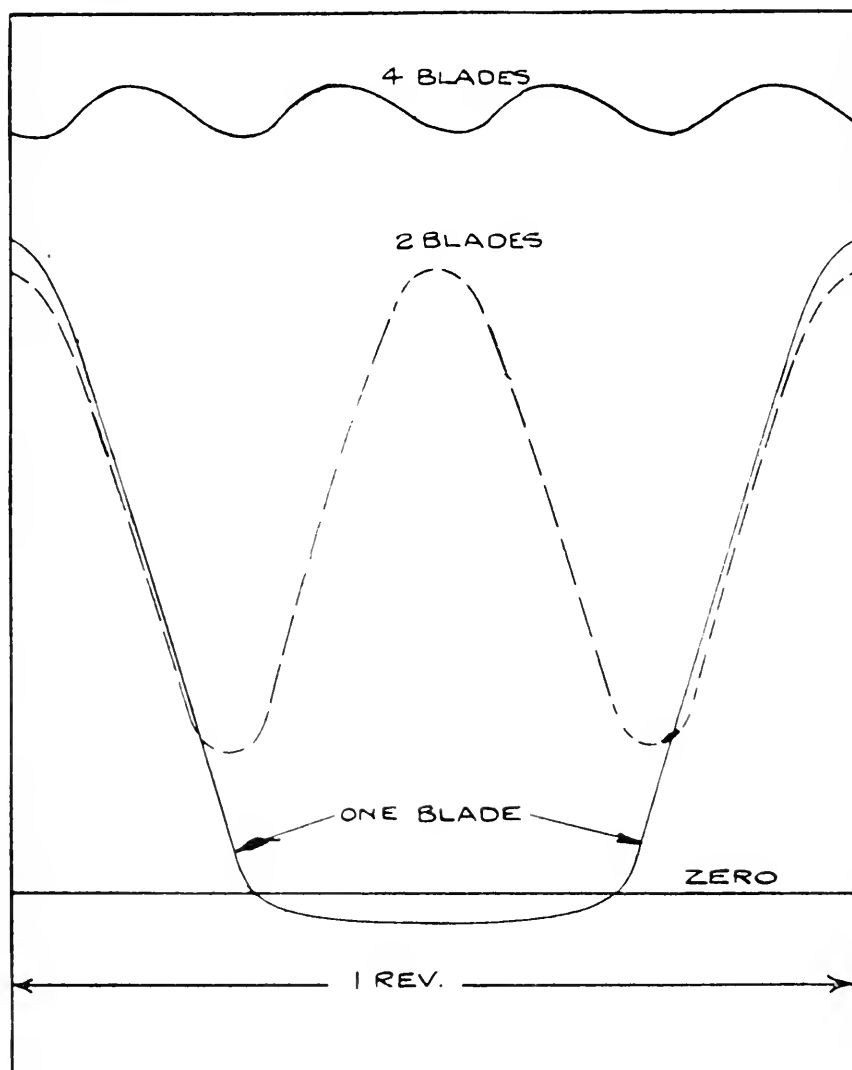
$$\begin{aligned} \text{Lift per blade} &= 107.10 - {}^6n^2 D^4 \\ \text{Drag per blade} &= 13.8.10 - {}^6n^2 D^4 \\ \text{Propulsive force per blade} &= 18.4.10 - {}^6n^2 D^4 \\ \text{Lift/drag} &= 7.75. \end{aligned}$$

With two screws 40ft. diameter, each with two blades, running at 1.1 r.p.s., we find a nett propulsive force of 14lbs. per blade, or a total of 56lbs., the forward speed being 86ft. per sec.

Now the drag of B.E.2E. body (R. and M. 440) is 57lbs. at 100ft. per sec., so that if these figures are realised it should be quite possible to obtain at least moderate forward speeds by this means.

13. Periodic Nature of the Forces in Non-Axial Motion of the Screw.

Since the angle of incidence and resultant velocity of each blade element varies throughout a revolution when the machine has forward motion, the thrust, torque, etc., on each blade will be periodic with a frequency equal to the speed of rotation of the airscrew. This is shown in Fig. 13 for the force X along the



PERIODIC VARIATION OF X .

FIG. 13.

airscrew axis, and the quantities Z and Q vary in a similar manner. The diagram refers to the blade (R.A.F. 6 section) calculated above. It will be seen from this that it will be almost essential to use four-bladed propellers in order to obtain anything like a uniform thrust and torque.

13a. Fixing the Screw Form.

We have considered each problem of screw design as if it were quite independent. It remains to be seen whether it will be best to design the screw for climb, hovering, forward motion, or descent. The above figures suggest that it will probably be necessary to design the screws to ensure safe descent with the screws running free. If we have a true screw then, when the blades are reversed for climb or hovering motion we shall have a bastard shape. Possibly it will prove best to use flat instead of helicoidal blades, but it looks as if the chief difficulty will be to design screws which will ensure safe descent in the event of engine failure. This matter I shall hope to treat in a subsequent paper.

14. Gliding Down an Inclined Path with Screws Free.

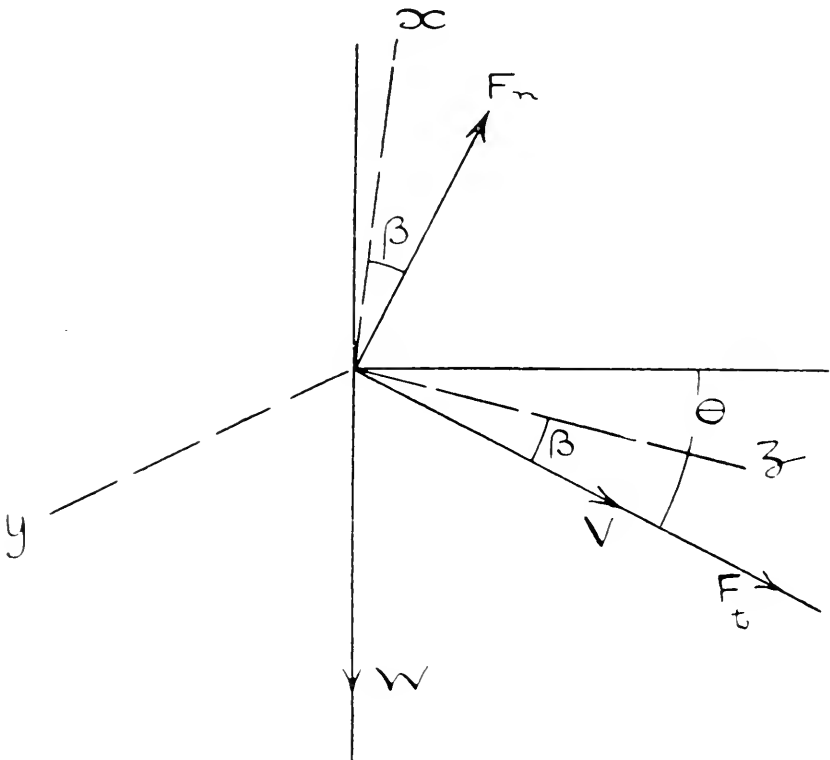


FIG. 14.

Let θ =inclination of flight path to the horizon.
Let F_n and F_t be the components of the forces on the airscrew normal and tangential to the flight path.
 W =the total weight.

Then

$$\begin{aligned} F_n \cos \theta - F_t \sin \theta &= W \\ F_n \sin \theta + F_t \cos \theta &= 0 \\ \therefore \tan \theta &= -F_t/F_n \end{aligned}$$

TABLE V.

	V/nD	0	1	2	3	4	5
$10^6 F_t/n^2 D^4$	$\beta = 0$	0	-49	-156	-350	-725	-1130
	$\beta = 15^\circ$	20	-77	-220	-490	-960	-1470
	$\beta = 30^\circ$	65	-136	-322	-680	-1280	
	$\beta = 60^\circ$	120	-196	-425	-850	-1740	
	$\beta = 90^\circ$	147	-234	-460	-970	-1890	
$10^6 F_n/n^2 D^4$	$\beta = 0$	-150	-238	-268	-245	-170	0
	$\beta = 15^\circ$	-150	-196	-180	-38	+265	755
	$\beta = 30^\circ$	-135	-87	0	+245	620	1100
	$\beta = 60^\circ$	-70	+49	176	350	550	830
	$\beta = 90^\circ$	0	0	0	0	0	0

15. Experimental Figures.

W. Margoulis has given* some experimental results for screws driven as windmills with their axes inclined to the wind. Some of these are given here in English (pound, feet, second) units in Table V. and Fig. 15. The pitch of the screw is 0.8D.

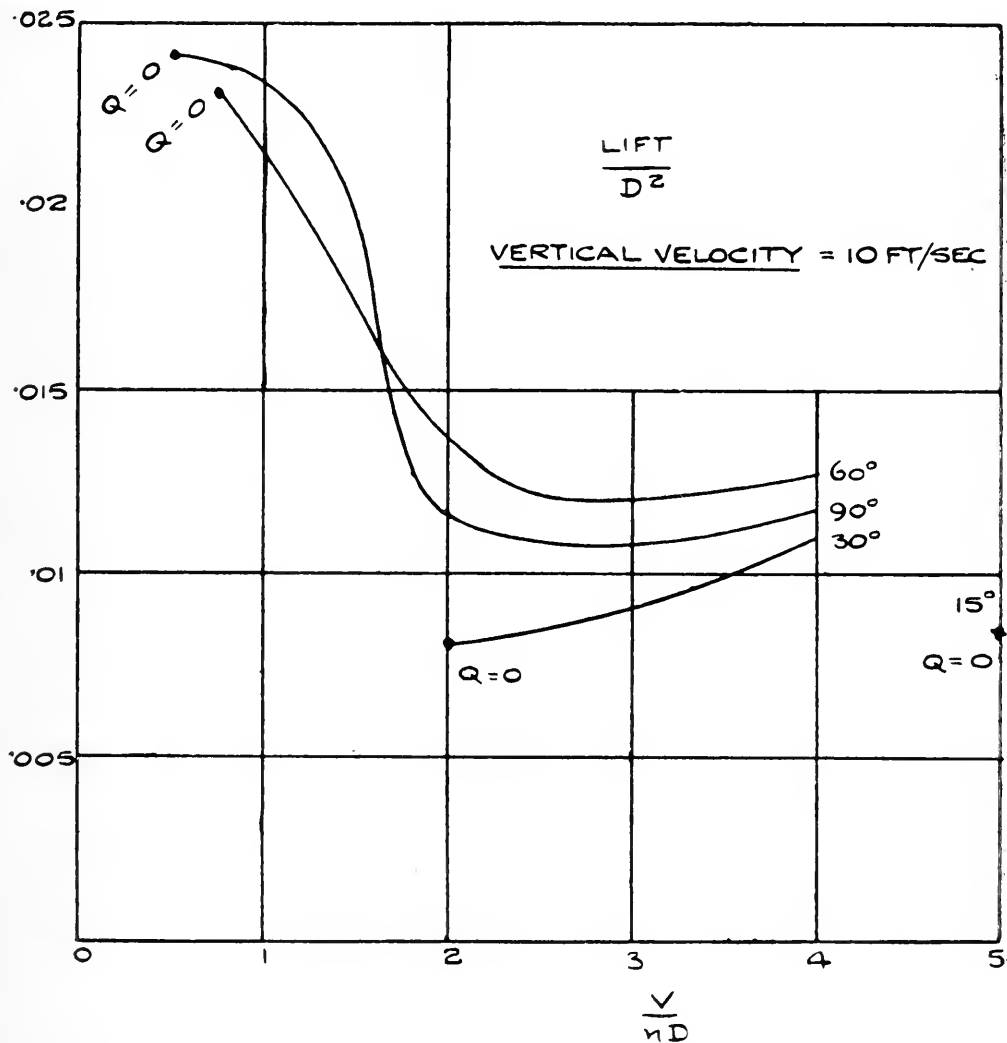


FIG. 15.

When the couple on the shaft is zero :—

β	15°	30°	60°	90°
V/nD ...	5	2	0.75	0.5
$10^6 F_t/n^2 D^4$...	—1470	—322	—130	—60
$10^6 F_n/n^2 D^4$...	755	0	0	0

From these figures have been deduced the curves of Fig. 15, showing the vertical lift when the machine is falling with the axis of the screw making different angles with the normal to the flight path. The curves are only plotted over a region where a braking couple (Q) is applied to the screw. The gliding angle is

* Supplement to L'Aéronautique, No. 34.

not found to be less than 60° . It will be seen that the lift is nowhere greater than when the airscrew axis is vertical and the torque zero. I do not think these figures are very conclusive; the pitch of the screw is too great and much better results should be obtained with a screw of pitch $0.2D$ or $0.3D$.

16. Gyroscopic Forces.

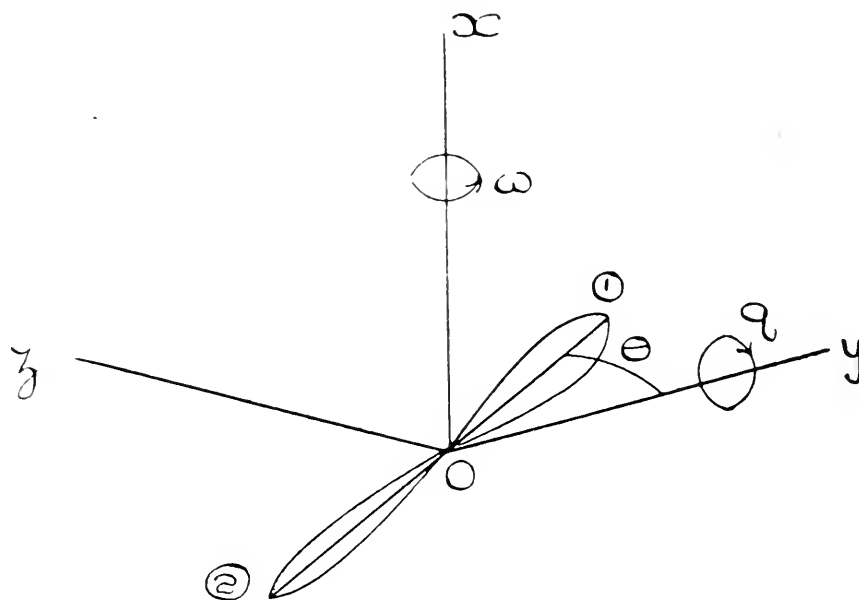


FIG. 16.

Let the axis of x be taken along the axis of rotation of the screw.

Let ω be the rotational speed of the screw.

θ be the angular position of blade (1) measured from the axis of y .

I_1 be the moment of inertia of the blade about Ox . Then, if A, B, C, \dots have their usual meanings, we have:—

$$\begin{aligned} A &= I_1 & D &= I_1 \sin \theta \cos \theta \\ B &= I_1 \sin^2 \theta & E &= 0 \\ C &= I_1 \cos^2 \theta & F &= 0 \end{aligned}$$

Now let the screw have an angular velocity q about Oy . Then the angular momenta are

$$\begin{aligned} h_1 &= I_1 \omega \\ h_2 &= Bq = I_1 q \sin^2 \theta \\ h_3 &= -Dq = -I_1 q \sin \theta \cos \theta \end{aligned}$$

The couples acting on blade (1) are:—

$$\begin{aligned} \text{About } Ox: \dot{h}_1 + qh_3 &= -\frac{1}{2}I_1 q^2 \sin 2\theta \\ \text{,, } Oy: \dot{h}_2 &= I_1 q \omega \sin 2\theta \\ \text{,, } Oz: \dot{h}_3 - qh_1 &= -I_1 q \omega \cos 2\theta - I_1 q \omega \end{aligned}$$

If there are two blades the resultant couples are

$$\begin{aligned} &-\frac{1}{2}Iq^2 \sin 2\theta \text{ about } Ox \\ &I\omega q \sin 2\theta \text{ about } Oy \\ &-I\omega q (1 + \cos 2\theta) \text{ about } Oz \end{aligned}$$

where I is the total moment of inertia.

If there are more than two blades the only couple is $-I\omega q$ about Oz .

These are the couples acting on the propeller; equal couples with opposite signs act on the helicopter.

With two similar propellers, each with two blades, rotating at the same speed in opposite directions, the couples acting on the helicopter are:—

$$-\frac{1}{2}Iq^2 (\sin 2\theta_1 - \sin 2\theta_2) \text{ about } Ox$$

$$I\omega q (\sin 2\theta_1 - \sin 2\theta_2) \text{ about } Oy$$

$$-I\omega q (\cos 2\theta_1 - \cos 2\theta_2) \text{ about } Oz$$

If q is small in comparison with ω the couple about Ox is negligible.

If the screws start rotation with their blades in line, or parallel if on different axes, all the couples acting on the machine will be zero. If they have more than two blades there will never be any resultant couple. In both cases, of course, the stresses involved by the couples balancing out among themselves will have to be considered.

(To be continued.)



STABILITY CALCULATIONS IN THE PROCESS OF DESIGN.

BY JOHN D. NORTH.

It cannot fail to be a subject for remark that in spite of the very large amount of work which has been done in this country on the subject of formal stability calculations, these calculations do not form a part of routine design of the majority of aircraft firms, nor are they used by the Air Ministry as a standard process of checking the aerodynamical qualities of an aeroplane. I use the term "formal" stability calculations to cover the solutions of the equations of motion of an aeroplane in rectilinear flight developed from Bryan's work.

From the remarks made by Commander Hunsaker in his Wilbur Wright Lecture it may be inferred that a similar situation exists in the United States, and I understand from M. Toussaint that such calculations are not customary in France. A discussion of the causes from which this situation has arisen will, I think, be of interest to those engaged in stability work.

The first and prime cause of this apparent neglect is a very simple one. The aircraft designer, whether he is employed by a commercial firm or by a Government department, is compelled to adjust his work to suit the specified requirements of his market. The aeroplane which is stable, in the true sense of the word, has a marketable value very little in excess of that of the machine which is reasonably easy to fly, and it has been found that by devoting the limited resources available to the improvement of performance better financial returns are assured. This may be, and I think is, an unsatisfactory state of affairs, but it nevertheless exists.

Secondly, the formal investigation of stability is not insisted upon by the Air Ministry in the manner in which the structural design is checked. A certain set routine has been adopted for the verification of the structural strength of aircraft, and is required as a condition of contract in the case of service machines, and by Act of Parliament so far as civil aeroplanes are concerned. There has, however, been no official pressure brought to bear to ensure that stability work which is not demanded by market conditions is carried out in the interests of service aviation or public safety.

Thirdly, it has never been completely demonstrated that the results of such calculations accurately represent the stability characteristics of the aeroplane as designed. Although many years ago an aeroplane, which was apparently stable over at least a part of its very limited speed range, was produced as the result of the worthy experimental efforts of the late Edward Busk and Robert Mayo; this aeroplane was not rendered stable by designing in accordance with the formal process, but by ingenious empiricism, trial and error, and devoted and dangerous experimental flying. It is true that this aeroplane has been the subject of subsequent calculations and flying tests, but these tests have not been sufficiently complete to verify the accuracy of the calculations, in fact in so far as longitudinal damping is concerned the values of M_q , the only rotary derivative deduced from quantitative tests, have not shown good agreement with the estimated figures.

When we consider all these facts, it is perhaps hardly surprising that those engaged in the design of aircraft do not embark on the long and arduous processes of developing a method of design which they are not satisfied will repay them for their work. If all performance testing had been confined to the casual reports of the pilot that the aeroplane appeared to fly fast or slow as the case may be, to have a good or moderate climb, or to reach a considerable or low altitude, there would hardly have been the incentive to improve performance

which exists as the result of the detailed investigations in this direction carried out at the official testing stations. Here, at least, there is a possibility of making a comparison of results with estimates without which it is difficult, if not impossible, to make any real progress in a design method.

Under present normal conditions it is only possible to judge the stability characteristics of an aeroplane from the qualitative report supplied by the pilot. A report, which even with the best intentions, is always somewhat unreliable and apt to be coloured by the characteristics of the machines which the pilot has been flying immediately prior to the tests in question. It has been my experience that so far as it is possible to judge the results of stability calculations from such reports, the formal process of stability calculation and design gives results which are even more satisfactory than might reasonably be expected from the known inaccuracies involved.

In order to verify, in some measure, the routine system of stability calculations which they had developed, Messrs. Boulton and Paul carried out a series of experiments with a small aeroplane which was definitely unstable over a large part of its speed range, by making modifications in this aeroplane and estimating their effect on the stability of the machine, and thus compared to some extent quantitatively their calculations with the full scale results obtained by observations of the air speeds at which certain phenomena occurred.

The results of these experiments were entirely satisfactory, although very limited in scope, and it was sufficient encouragement to justify further development of the routine process so that the calculations, which in the case of the first aeroplane extended over nearly a year, can now be carried out in a few weeks. It is hardly possible, however, to make any further real advance until accurate experimental results can be obtained; as the result of the calculations made in the course of design, the periodicity and damping of the long and short longitudinal oscillations over the whole of the flight range, in level, climbing and gliding flight, are determined, as are also the rolling and spiral subsidences and the yawing oscillation over the same range. Qualitatively, the machines seem to show results of flight which accord with expectation, but it is obvious that quantitative measurements are imperative to check the assumptions made.

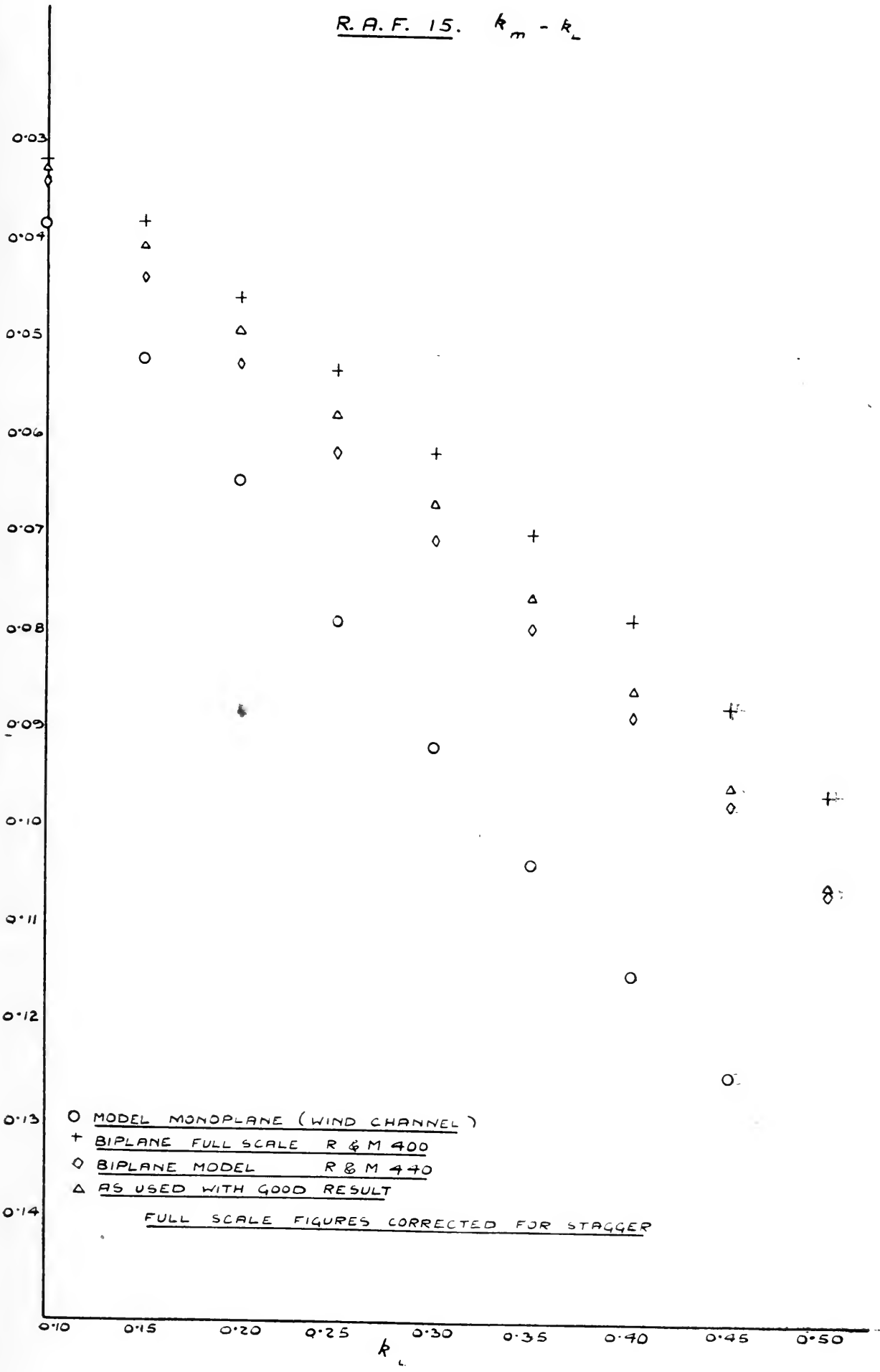
The principal difficulty experienced in the process of design is, of course, the estimation of the derivatives. With the exception of X_q it is possible to write down a series of expressions from which the derivatives may be calculated from existing aeronautical data coupled with certain specific wind channel tests, carried out on the ordinary balance. In addition to this, experiments may be made on an apparatus for directly determining the rotary derivatives, and experiments of this type have been carried out at the N.P.L. and elsewhere for some years past. Although such inference might not be drawn from the published results, these latter experimental measurements have only quite recently been satisfactory. Torsional oscillations in the spindle connecting the model with the indicating or recording apparatus had previously disturbed the experiments as to give rise to varying results with different moments of inertia of the apparatus.

Mr. A. R. Relf has recently pointed out the cause of these inaccuracies and has devised an apparatus whereby the motions of the model are transferred to the indicator or recorder by tension wires, and he has further introduced a system of forced oscillations previously only employed in the measurement of the compound derivatives L_r and N_p . Valuable evidence can be obtained by carrying out a series of tests with this apparatus and comparing the figures obtained with those given by the approximate expressions; there is, however, every reason to believe that wind channel results are not directly applicable to full scale flight, as scale effect is important in the value of the slope of the moment curve at various altitudes. Fig. 1 illustrates a number of model tests compared with those obtained by full scale experiment on the R.A.F. 15 wing section, and shows the large

discrepancies which may arise, even in the case of this section concerning which there is an exceptionally large amount of experimental data. In order to determine the relative attitude of the various surfaces under different conditions of flight, it is necessary to estimate very carefully the conditions governing the equilibrium of the machine, and these again are rendered doubtful by the uncertain value of the moments, while they are still further complicated by the presence of the slipstream, which affects not only the downwash but also the direction of the wind relative to the vertical surfaces. The variation or directional trim, engine on and engine off, is a problem of some importance in considering uncontrolled flight. To overcome this variation it has been proposed to set the engine obliquely in plan, but it is doubtful whether it is practicable to affect a complete trim on a high power machine in this manner. The value of the downwash angle from the main planes is also a matter of difficulty, as although this has been made the subject of considerable study the conditions from aeroplane to aeroplane are varied by interference effects. In considering lateral and directional stability, the effect of the airscrew on Y_v , N_v and N_r is very important, particularly in the case of N_v , in which it is responsible for the largest term. Approximate expressions have been suggested for estimating the side force on the airscrew due to yaw (see R. and M. 427), and by the use of these expressions it is possible to include the effect of the side force in the derivatives. The accuracy of these assumptions requires special checking and further investigations are required into the fin effect of the propeller stopped or running freely as in a glide. It is possible that experiments in the new N.P.L. duplex channel on a model complete with propeller may throw some light on this point.

For the longitudinal derivatives it is probably possible to obtain a fairly accurate forecast from existing data without special wind channel tests. This is due to the conventional forms of tail planes and sections in general use, and the relative unimportance of the body in M_w and M_q . If, however, there were any peculiarities in the design of the aeroplane, wind channel tests would certainly be necessary. In the case of lateral and directional stability the body is of more importance and the forms of the vertical surfaces vary greatly from machine to machine. Due to the desire to present a pleasing appearance to the eye, the fin and rudder are generally of curious outline aerodynamically, and an estimation of the characteristics of these surfaces and the interference effect of the body thereon would be a matter of extreme difficulty without wind channel tests. Under these circumstances the experimental determination of $dY/d\psi$ and $dN/d\psi$ for the body, fin and rudder are necessary. These tests are neither difficult nor expensive and they do not involve the delay and cost of manufacturing the complete model, the metal aerofoils of which represent an elaborate piece of work. It is not an exaggeration to say that a complete model of an aeroplane to be really useful for wind channel work, costs from £400 to £500 and takes several months to produce. The models necessary for the wind channel tests on the body, fin and rudder cost only a small fraction of this sum and can be produced in a few weeks. The characteristics of the aeroplane depending on the distribution of its mass can be ascertained without much difficulty and with a fair degree of accuracy. With the customary axes passing through the centre of gravity the Y axis is a principal axis by symmetry, the only product of inertia arising is in respect of the XZ axes, and has been found to be a term of negligible importance. The accuracy of the first calculations of the moment of inertia can be subsequently checked from the detail weights of the aeroplane and it would not be a difficult matter to verify these values experimentally, though the necessary rig would be somewhat expensive.

Stability calculations should properly form the basis of the estimation of the loads likely to come on an aeroplane flight and furnish the required basis for the determination of controllability. At the present time the loads on an aeroplane for purposes of strength calculations are assumed by a very rough and ready system, which has no real justification, and in view of the immense importance



of weight economy, it is extremely likely that the material used in the construction of an aeroplane is not disposed of to its best advantage. So far as the estimation of controllability is concerned the difficulties of the ordinary stability calculations are accentuated, but even with the present information available it seems possible to get a very good idea of the control characteristics of an aeroplane with the assistance of wind channel data relating to the control surfaces. It is, of course, a fairly easy matter to appreciate after the calculations on a number of aeroplanes what are the important characteristics governing the stability of a machine, as for example the position of the centre of gravity, the sizes of the control and stabilising surfaces and the leverages through which they act. If it were not so these calculations, which are actually a process of trial and error, would be far more laborious than is actually the case, but in spite of the facility with which many of the characteristics of the stable aeroplane have been adopted by aircraft designers without the subsequent verification by stability calculations, accidents, apparently traceable to instability, still seem to arise and it is probable that they will continue to occur until stability work is seriously treated as a routine part of design and test flying.



GAS ARMOUR FOR AIRCRAFT.

BY F. L. M. BOOTHBY.

The greatest deterrent to the growth of air travel is the fear of fire in the minds of potential passengers. It is not a groundless fear, for there must be few members of this Society who have not lost friends and acquaintances from this cause. Unfortunately, the fuel at present in use in all aircraft is of a highly inflammable nature, as is the hydrogen with which airships are filled. So long, however, as oxygen can be kept from mixing with the gas or fuel a fire cannot occur. The problem of abolishing the risk of fire in the air resolves itself into finding the best method of excluding the oxygen from the combustible material. The means adopted must be light, otherwise the aircraft could not use them, cheap and capable of application in any part of the world.

In the exhaust gases from our internal combustion engines we have a completely non-flammable gas, which will render any fuel or gas safe so long as it is the only material in contact with it.

Every aircraft therefore carries its own antidote to the fire danger if only it can be applied. Let us consider the case of the aeroplane first. Here the danger of fire lies in the structure of the machine being set on fire by the engine or wireless apparatus; and secondly, fire in the fuel. Fire in the structure can generally be avoided by good design, and if it does occur is of a minor nature and can be dealt with by means of the usual fire extinguishing appliances. Fire in the fuel is a different matter. In peace time it may occur through a leak developing in the fuel tank or fuel system and so allowing an inflammable mixture to accumulate in the aeroplane. This mixture may be fired by a spark from a loose terminal in the wireless or other electrical gear, including the ignition system, by sparks from the exhaust, and also I am inclined to believe from the statical discharge which may take place between the aeroplane and the ground, and certainly from the heavy sparking which occurs if the aerial is in use in a thundery state of the atmosphere. In war time we have to add the action of incendiary bullets to the means by which the fuel may be ignited.

Should the ordinary fuel tank spring a leak, accidentally or through hostile action, the escaping petrol gains immediate access to the air and the fuel and its vapour is free to go to any part of the aeroplane into which it may be blown. It is a simple matter, however, to enclose the petrol tank in an outer casing, which may be partly formed of the fabric fairing of the fuselage. From this outer casing a drain pipe may be carried to the bottom of the skid or other place of safety. It is also a simple matter to fill the space between the fuel tank and the outer casing with a supply of non-flammable gas by leading a small metal pipe into it from the exhaust pipe, this pipe being of sufficient length to cool the gas during its passage through it.

If now an incendiary bullet, or even a Very's light, is fired into the fuel it will not catch fire. This method of protection is quite satisfactory for small leaks, but trials of safety fuel tanks at Farnborough show that further steps must be taken to deal with the case of a large leak near the bottom of the tank. In this case it will be found that petrol may squirt from the hole under pressure and out of the hole, or holes, in the outer casing where, not being under the protection of the inert gas, it may be set fire to. The simplest method is to provide another layer of fabric or other material between the fuel tank and outer

casing so that the holes made would have to be in such a position that the petrol jet, falling under the action of gravity, would find the three holes in the correct position to allow it to reach the outer air. This might happen if a large number of rounds were fired close together, but is unlikely. It is better therefore to place a material such as a sponge, and preferably rubber sponge, outside the petrol container, as if this does not close the bullet hole and stop the leak entirely it reduces it to a slight trickle and the petrol, remaining in the inert gas, cannot be ignited. By passing a loose fabric sleeve doped with petrol proof dope, or lined with goldbeater's skin, over the petrol pipes it is possible to keep the whole fuel system under the protection of the gas armour up to and including the float chamber of the carburetter, and should a pipe break the petrol would flow back along this outer fabric pipe (it may be metal if desired) back to the casing of the petrol tank and from there drained away to a place of safety.

As an extra precaution it would be possible to place all accumulators, wireless gear, etc., in a gastight tank of fabric or other material and keep this fuel of inert gas, so that "shoots" occurring in a crash or otherwise and causing sparks would be unable to set fire to anything.

Airships.

In this type of aircraft the problem of protecting the fuel from fire is the same as in the aeroplane. In rigid airships it is the custom, at present, to stow the fuel along the keel and it should not be difficult to enclose the whole of the petrol tanks in a gastight fabric tunnel and fill the space round them with non-flammable gas. The main trouble is that exhaust gases are poisonous and arrangements would have to be made for blowing through the space round the tanks before they could be inspected.

In passenger airships the keel is required as a gangway for passengers entering or leaving the airship, in which case the petrol tanks are at present in the way and would be more of a nuisance still if covered in and surrounded by a poisonous gas, while the increased weight is also an objection. It has long been the practice to carry the fuel tanks of non-rigid airships on the side of the ship and it is thought that this should also be done in rigids. The tanks should be built into the structure of the main horizontal longitudinals, when the metal used in the construction of the tanks would also add to the strength of the ship, which is not the case at present. If all the electric leads are carried along the bottom of the keel in a tube filled with non-flammable gas there would be little chance of the fuel being ignited should the ship break, as in R.38. Fortunately, we can now see our way to abolishing the use of petrol in airships, so that with the electric leads gas armoured and a heavy fuel stowed on the side of the ship there should be reasonable safety in peace practice, and gas armour round the tanks would protect them from incendiary attack in war.

We have now to consider the question of protecting the gas with which an airship is filled.

Experiments have proved that if you have a layer of non-flammable gas some six inches thick round hydrogen, it is possible to fire a Very's light into the hydrogen container. The Very's light will continue to burn till it has made a hole in the bottom of the hydrogen bag, and then in the outer cover through which it will fall, still incandescent, but without setting fire to the hydrogen. The same experiment may be conducted with incendiary bullets. The non-flammable gas must be at a slight pressure, so that air does not gain admittance through the holes made. It will be found that as soon as the non-flammable gas loses pressure air leaks in and hydrogen leaks out fairly rapidly, and a subsequent incendiary attack in the same locality will cause a fire. The problem then is how to maintain your protective gas under pressure. Supposing the space between the gasbags and outer cover to be completely filled with nitrogen, which is the

most suitable commercial gas for the purpose as it is no heavier than air, it can be maintained under pressure so long as the airship continues to rise slowly, and a very large hole would have to be made in her outer cover before the pressure would fall with the airship climbing at her maximum speed.

Helium would be a very desirable gas to use for protective purposes as its lift is within 5 per cent. of that of hydrogen. It is probable that in the fighting airship of the future double gasbags will be used, the outer filled with helium and the inner with hydrogen. It is highly improbable that hydrogen will be absent altogether in such an airship owing to its value as fuel, but on going into action the airship can rise till all the hydrogen is blown off and only helium remains.

For commercial purposes we must tackle the problem in rather a different way. We do not want the expense of buying helium or even nitrogen. We have available the non-flammable gas from the motors, but this has the disadvantage of being heavier than the air it displaces and the piping for cooling the gases down to a temperature which will permit of their being put round the hydrogen without damage to the fabric also involves weight. Nevertheless, it is considered to be worth it, an advantage gained is that the water in the exhaust will be condensed and fall to the bottom of the outer cover where it can be collected and used as ballast. A disadvantage is that it is poisonous and that the crew would have to use gas masks when working in its vicinity.

The extra weight involved will be these masks, say 100lbs., making outer cover proof to water and CO_2 , and isolating the trunks through which hydrogen is valved to the atmosphere, say 500lbs. Gas valves in outer cover, which should be on top so that air will be pushed out of them as the exhaust gas enters at the bottom, say 100lbs., and the gas cooling apparatus on the engines at 100lbs. each, 600lbs., a total of 1,400lbs.

Distance pieces would have to be inserted between the gas containers and the outer cover to allow the protective gases to flow round which would slightly increase the above figures.

In a commercial ship we do not expect to have to deal with incendiary attack and the means by which our hydrogen may be set alight are reduced to fire in a car, electrical defect, or lightning. Ships have been lost in thunderstorms, but there is a case of a Zeppelin struck by lightning and having all her bow girders fused together in the nose without harm being done. If lightning could enter the gasbag without hydrogen coming in contact with air a fire could not occur. The most likely places for a ship to be struck are in the bow or stern, at the highest point amidships, where a lightning conductor should be placed and above the cars. The hot exhaust gases are good conductors of electricity and a ship under way in a thunderstorm leaves a conducting trail behind along which lightning may travel. If the aerial is out this is an additional source of danger. It is easy to place a small bag of non-flammable gas above each car, at the bow and stern and under the top lightning conductor. It only necessitates a $\frac{1}{2}$ in. pipe fed from the exhausts of the engines and led into these bags which can be open to the atmosphere through another small opening on the top, very little weight is involved, say 200lbs. all told. With similar protection over the passenger car it is probable that the gas in the commercial airship is as well protected as is necessary. These pads of non-flammable gas over the engine cars also give protection in the case of a fire in the car, provided it is a small one, as it should be, as there should not be sufficient fuel in a power car at any time to permit of a large fire. This gas protection over the engines was incorporated in the original design of the R.23 class, where the engines were carried in the keel, giving a saving of about two tons weight and an increased speed of two knots, compared to the modified design with cars. If the methods

suggested to protect the fuel from a defect in the electric wire leads are adopted they will also be sufficient in the case of the hydrogen.

Further experimental work is required to determine the thickness of the layer of non-flammable gas necessary to protect against incendiary attack in relation to the pressure at which it is maintained. The thicker the layer the greater will be the head resistance of the airship and the greater the sacrifice that will have to be made, exactly as in the case of armour protection in surface ships. Once the principle of armouring aircraft is adopted we may confidently look forward to the old contest of guns versus armour being fought out all over again in the air.



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All communications should be addressed to the Editor.

No. 143.

NOVEMBER, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Elections.

The following new members were elected at a Council meeting held on October 17th:—

Associate Fellow.—H. F. Parker.

Students.—W. H. Brown, P. B. Humphrey, C. J. Sanders and F. E. Siggers.

Associate Member.—M. F. Wren.

SCOTTISH BRANCH.—*Associate Member.*—Cecil Veitch.

Examination.

The Council announce the following list of successful candidates in the Associate Fellowship Examination held on September 26th:—

*K. W. Berger (Theory of Structures, etc.).

S. H. Evans (Theory of Structures, etc., and Aerodynamics).

T. A. Kirkup (Theory of Structures, etc., and Aerodynamics).

H. J. Mackintosh (Theory of Structures, etc., and Aerodynamics).

*G. E. Page (Theory of Structures, etc.).

*S. O. Smith (Theory of Structures, etc.).

S. E. Taylor (Heat Engines and Meteorology and Navigation).

* These candidates already possessed qualifications which exempted them from the necessity of taking the paper in Aerodynamics.

Lectures.

Owing to the continuance of rebuilding operations at the Royal Society of Arts members are asked to note that Major A. R. Low's lecture, "A Review of Airscrew and Helicopter Theory, with Aeroplane Analogies," will take place at 5.30 p.m., in the theatre of the Royal United Service Institution, Whitehall, on Thursday November 2nd.

Donations.

Professor Leonard Bairstow has presented to the Society's Loan Collection the lantern slides used by him in his lecture on "The Work of S. P. Langley."

The Council have accepted an offer from Major Wilfred T. Blake to present to the Society's Library a copy of the notes of his flight from London to Calcutta and of a number of photographs taken en route.

Students' Section.

The annual meeting of the Students' Section was held in the Library, at 6.45 p.m., on October 12th, when Mr. T. C. Sharwood was appointed Honorary Secretary in succession to Mr. S. H. Evans. It was decided that each college or group of students should nominate a student to represent it and to further the interests of the Students' Section in the particular college or group concerned.

The annual meeting was followed at 7.30 p.m. by the inaugural address of the session from Dr. A. J. Sutton Pippard on "The Aeroplane Considered as an Engineering Proposition," illustrated by lantern slides.

Forthcoming Arrangements.

- Nov. 1, *Scottish Branch*, 8.0 p.m.—Sir Sefton Brancker, Associate Fellow, "The Latest Developments of Civil Aviation," Royal Technical College, Glasgow.
- „ 2, 5.0 p.m.—Major A. R. Low, Fellow, "A Review of Airscrew and Helicopter Theory, with Aeroplane Analogies," Royal United Service Institution.
- „ 8, *Scottish Branch*, 8.0 p.m.—Professor Gordon Gray, "Research Work on the Application of Gyroscopes to Aeronautics," Glasgow University.
- „ 9, 7.30 p.m.—*Students' Meeting*.—Mr. H. C. Brown, "Airships." Chairman, Lieut.-Col. W. Lockwood Marsh. Library.
- „ 16, 5.0 p.m.—Mr. R. McKinnon Wood, Fellow, "The Co-Relation of Model and Full-Scale Work," Royal Society of Arts.
- „ 21, 4.0 p.m.—Library and Publications Committee.
4.30 p.m.—Candidates' Committee.
5.0 p.m.—Council.
- Dec. 6, *Scottish Branch*, 8.0 p.m.—Major J. S. Buchanan, Associate Fellow, "The Latest Developments in Aeronautical Research," Royal Technical College, Glasgow.
- „ 7, 5.30 p.m.—Professor C. Frewen Jenkin, Fellow, "Fatigue in Metals," Royal Society of Arts.

W. LOCKWOOD MARSH.



PROCEEDINGS.

FIRST MEETING, 59th SESSION.

The first meeting of the Session was held at the Royal United Service Institution, Whitehall, London, on Thursday, October 5th, Prof. L. Bairstow presiding.

The CHAIRMAN said that before vacating the chair and reading his paper he had a very pleasant duty to perform in the acknowledgment of work done by members of the Society during the past year. As they all knew, the Society gave medals to its members on special occasions. The gold medal had been awarded by the Wright Brothers to Mr. Busk, Professor Bryan, and one or two others, but it was very rarely given. They also had a silver medal, which, during the past eight or nine years, had been still more rarely given. The Council, however, had decided to establish a regular custom, and in future the silver medal was to be awarded annually to the person—not necessarily a member—who read before the Society the best paper, or who had the best paper published in the Journal of the Society. From possible recipients of that award had been excluded the Wilbur Wright Memorial lecturers and also those for the R.38 Memorial and the Busk and Osborne Memorials. The Council, having considered the papers presented during the past year, had decided to award the silver medal to Mr. Ricardo for his paper on "Some Possible Lines of Aero Engine Development."

The medal was presented to Mr. Ricardo amid applause.

The Chairman, continuing, said there was also a bronze medal of the Society, which was intended to recognise special merit as judged from papers published in the AERONAUTICAL JOURNAL which had been written by students. The bronze medal was not awarded this year, but it was hoped that, with the growth in the strength of the Students' Section, there would be occasion to award it in the coming year. In addition, mainly through the encouragement of one of the members of the Society, a new prize had been instituted during the year—the Pilcher Memorial Prize; this prize was also limited to students, and for this year had been awarded to Mr. Evans for his paper on "Some Notes on Commercial Aircraft."

A set of books was then presented to Mr. Evans.

The Chairman said this concluded the first part of the proceedings, and as it would be rather difficult for him both to take the chair and to read a paper, he would ask Major Wimperis to act as Chairman for the remainder of the proceedings.

Major WIMPERIS, on taking the chair, said that Col. Mervyn O'Gorman should have been in the chair, but he was not in the country at the present time as he was travelling in Italy and attending a Conference in Rome. In the absence of Col. O'Gorman, therefore, the duty fell upon himself to take the chair, and he was the more glad to do so because it gave him an opportunity to refer to the personality of the incoming President, Prof. Bairstow. He had known Prof. Bairstow a very, very long time. They were students together at about the same time in the Imperial College of Science, and he remembered that for several decades there the most brilliant student that had been produced by the College was their incoming President. He remembered that Prof. Bairstow had an uncanny faculty of making himself acquainted with, and making completely original suggestions on, subjects which they did not think he knew anything about. At any rate, people who did not know him well thought that perhaps

he did not know anything about them, but those who got to know him, as his fellow students did, were prepared for anything, and things were brought to a head, so to speak, at a meeting of the Institution of Civil Engineers, when the subject under discussion was, as far as most people knew, rather off the track of the immediate interests of Prof. Bairstow; but he showed himself not only very completely acquainted with it, but made the most fundamentally interesting and suggestive proposals for further work. Therefore the Society was to be congratulated in having at its head, during the coming Session, Prof. Bairstow. His work in the field of aeronautics was so well known that he need not dilate upon it at all, and he would therefore call upon Prof. Bairstow to give his lecture.

THE WORK OF S. P. LANGLEY.

My special object in choosing the subject of to-night's lecture was to draw attention to a first-rate example of systematic inquiry, the type of inquiry properly called scientific. Progress was made step by step in the face of formidable difficulties, and no attempts were made to solve the problems of mechanical flight by bursts of brilliance of the type known as the invention of genius. To my mind this, the scientific method, is most suitable for the great bulk of human endeavour, and we should accept the phenomenal leaps of some individuals as the exception rather than the rule. The influence of Langley lies in the force of example and the spirit of his work rather than in the permanence of his data. It is probably not wide of the mark to say that the experimental results of Langley are now rarely appealed to, since they have been succeeded by others of greater accuracy and more immediate applicability, and yet who can doubt that the whole course of aviation was largely determined by the efforts of this one man. Without him I think it almost certain that flying would not have been ready for the Great War, with consequences which we can imagine.

Langley's work is described, largely by himself and his immediate colleagues, in two or three volumes of which the most bulky is the "Langley Memoir on Mechanical Flight," published in 1911. It is divided into two parts, the first, covering the period 1887 to 1896, written by Langley, and the second, 1897 to 1903, by Charles M. Manly, assistant in charge of experiments. The end of this period is significant, coinciding almost precisely with the earliest successes of the Wright Brothers. The record after that date has been marred by the Hammondsport trials on the modified Langley aeroplane. I want you to leave those trials out of your account, for they have nothing to do with Langley and his methods.

Writing in 1901 Langley says:—*

"And now, it may be asked, what has been done? This has been done: A 'flying machine,' so long a type for ridicule, has really flown; it has demonstrated its practicability in the only satisfactory way—by actually flying—and by doing this again and again under conditions which leave no doubt.

"There is no room here to enter on the consideration of the construction of larger machines, or to offer the reasons for believing that they may be built to remain for days in the air, or to travel at speeds higher than any with which we are familiar. Neither is there room to enter on a consideration of their commercial value, or of those applications which will probably first come in the arts of war rather than those of peace; but we may at least see that these may be such as to change the whole conditions of warfare, when each of two opposing hosts will have its every movement known to the

* "The Langley Aerodrome."

other, when no lines of fortification will keep out the foe, and when the difficulties of defending a country against an attacking enemy in the air will be such that we may hope that this will hasten rather than retard the coming of the day when war shall cease."

This note was written before the advent of the man-carrying aeroplane—two years before. Some of the prediction is yet unfulfilled, particularly that as to remaining for days in the air, but the effort of imagination which expected war developments before civil, and the difficulties of defence against hostile aircraft, are now matters of general knowledge and common anxiety. He continues his story in a different but not less interesting strain.

"I have thus far had only a purely scientific interest in the results of these labours. Perhaps if it could have been foreseen at the outset how much labour there was to be, how much of life would be given to it, and how much care, I might have hesitated to enter upon it at all. And now reward must be looked for, if reward there be, in the knowledge that I have done the best in a difficult task, with results which it may be hoped will be useful to others. I have brought to a close the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight—and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world, indeed, will be supine if it do not realise that a new possibility has come to it, and that the great universal highway overhead is now soon to be opened."

In that short passage is much of interest; it points out the unknown amount of work involved in a particular piece of research, and that the reward is often in internal satisfaction and not commercial return. To the scientist the financial returns are, I think, rightly, less appreciated than the successful campaign against difficulties, though he must, since he belongs to the animal kingdom, pay such attention to the former as will keep body and mind fit for the task. Bodily, that is physical, fitness is as great an asset in scientific inquiry as in other branches of life, and few of us fail to realise some of the more obvious correlations of mind and matter dealt with scientifically by the President of the Royal Society at the meeting of the British Association for the Advancement of Science held at Hull this year.

I think Langley might well be satisfied with the help that he has given to others, though he might wish to reiterate his concluding paragraph to a world which has allowed 20 years to lapse without realising the value of the opening of the great universal highway. Possibly, however, he might exhibit some of the patience shown in his experimental work and see sufficiently steady if slow progress towards the goal he foresaw. On the commercial aspect, Manly has a word to say in his preface to the "Langley Memoir."

"Persons who care only for the accomplished fact may be inclined to under-rate the interest and value of this record (1911). But even they may be reminded that but for such patient and unremitting devotion as is here enregistered, the new accomplished fact of mechanical flight would still remain the wild unrealised dream which it was for so many centuries.

"To such men as Mr. Langley an unsuccessful experiment is not a failure, but a means of instruction, a necessary and often an invaluable stepping-stone to the desired end. The trials of the large aerodrome in the autumn of 1903, to which the curiosity of the public and the sensationalism of the newspapers gave a character of finality never desired by Mr. Langley, were to him merely members of a long series of experiments, as much so as any trial of one of the small aerodromes or even one of the earliest rubber-driven models. Had his health and strength been spared, he would have

gone on with his experiments undiscouraged by these accidents in launching and undeterred by criticism and misunderstanding.

"Moreover, it is to be borne in mind that Mr. Langley's contribution to the solution of the problem is not to be measured solely by what he himself accomplished, important as that is. He began his investigations at a time when not only the general public but even the most progressive men of science thought of mechanical flight only as a subject for ridicule."

It appears that the pursuit of knowledge requires some courage, and Langley impresses one as having been able to recognise home truths with detachment and humour. In one passage he says:—"It has taken me, indeed, but a few years to pass through the period when the observer hears that his alleged observation was a mistake; and the period when he is told that if it were true it would be useless; and the period when he is told that it is undoubtedly true, but that it has always been known." It sounds like modern history instead of 25 years ago, and I wonder how many cold shivers are passing down our backs at the thought that we may be saying such things ourselves. Of course it is not likely, but then——. Even Langley had periods of doubt and a feeling that he was beating the air, and he singles out the year 1895 as one which "gave small results for the labour with which it was filled"; and then comes the buoyancy:—"Shortly after its close, I became convinced that substantial rigidity had been secured for the wings; that the frame had been made stronger without prohibitive weight, and that a degree of accuracy in the balance had been obtained which had not been hoped for. Still there had been such a long succession of disasters and accidents in the launching that hope was low when success finally came."

Just one more quotation before becoming immersed in technics. The general unbelief of the world's inhabitants had its effect on Langley's experiments. He shrank into his shell, and Mr. Alexander Graham Bell records the "pleasure of witnessing the successful flight of some of these aerodromes more than a year ago, but Dr. Langley's reluctance to make the results public at that time prevented me from asking him, as I have done since, to let me give an account of what I saw." Langley himself makes it clear that in his view the public are not good observers of experiments, and says, "It is the practice of all scientific men, indeed of all prudent men, not to make public the results of their work till these are certain." That he was ready to give to the world complete accounts of his experiments, both successes and failures, without commercial motive, is clear. It may be that some such feelings on the part of scientific men lead to their withdrawal from public life, action which many of us deplore but understand. I don't suppose that it is the only reason, and with an awakening of business life to the value of science perhaps we may hope for an atmosphere in which both scientists and men of commerce may meet and continue to meet.

Langley dates his interest in flight as beginning in the years 1886-1887, whilst he was engaged in the study of astrophysics in Allegheny, Pa. At that time most of those now connected with aviation were children at school picking up some of the more elementary knowledge transmitted to us from past generations. Not only was it 35 years ago in total time, but it was rather more than 20 years prior to the first public exhibitions of man-carrying aeroplanes. Langley himself died in 1906, and so just failed to see a definite seal put on his speculations as to the future, although he was aware of the secret flights of the Wright Brothers, and took a great interest in their work.

The position at that time is clearly summarised by Langley:—

"I desire to ask the reader's consideration of the fact that even 10 years ago (*i.e.*, prior to 1897) the whole subject of mechanical flight was so far from having attracted the attention of physicists or engineers, that it was generally considered to be fitted rather for the pursuits of the charlatan

than for those of the man of science. Consequently, he who was bold enough to enter it, found almost none of those experimental data which are ready to hand in every recognised and reputable field of scientific labour. Let me reiterate the statement, which even now seems strange, that such disrepute attached so lately to the attempt to make a "flying machine" that hardly any scientific men of position had made preliminary investigations, and that almost every experiment to be made was made for the first time. To cover so vast a field as that which aerodromics is now seen to open, no lifetime would have sufficed. The preliminary experiments on the primary question of equilibrium and the intimately associated problems of the resistance of the sustaining surfaces, the power of the engines, the method of their application, the framing of the hull structure which held these, the construction of the propellers, the putting of the whole in initial motion, were all to be made, and could not be conducted with the exactness which would render them final models of accuracy."

Throughout his writings Langley made a clear distinction between two subjects which he called "aerodynamics" and "aerodromics," a distinction which still exists, but is differently described. His divisions correspond very closely with the modern expressions "performance" and "control and stability," both of which are now regarded as branches of aerodynamics. The scientific advisers of the Air Ministry are more and more turning to the study of "aerodromics" on which progress towards safety is seen to depend very largely. Its problems are very difficult at the present time, and in the absence of scientific executive direction progress will continue to be slow.

There is little present evidence of the spirit of Langley, which takes up a task so great that "to cover it no lifetime would have sufficed." Team work may be continuous, but the work of an individual is necessarily limited by the length of his active years of life. If, however, the team is to be steady it must be well guided, and we have yet much to learn in the methods of doing this. Would Langley, who saw so clearly the broad future of aviation, or a non-scientific man have been the better director of research?

Having so divided the field of inquiry, Langley first devoted his whole attention to aerodynamics and to the establishment of certain fundamental data on which to base estimates of the performance of heavier-than-air craft. His chief piece of apparatus was a whirling table 60ft. in diameter, near the Allegheny Observatory; in 1889 it was surrounded by an octagonal fence 20ft. high open to the heavens in an attempt, which proved to be ineffectual, to ward off some of the disturbances due to wind. His last word of advice on this subject was: "If any one should propose to repeat or extend these experiments, I would advise him, first of all, and at all costs, to establish his whirling table in a large, completely inclosed building."

When, in 1909, the Advisory Committee for Aeronautics was formed, and decided to build a whirling table at the National Physical Laboratory, this advice was followed with success. Time has, however, shown that the wind channel is a much more suitable piece of apparatus for the purpose, and we now have that fund of knowledge, the lack of which was felt so acutely by the early pioneers. It is to this fact in large measure that we must attribute the possibility of appreciable numbers of designers and workers in aviation and not to any development of unusual character in the powers of the human mind.

After trying to work the whirling arm with a gas engine of $1\frac{1}{2}$ h.p. without satisfaction, a steam engine of 10 h.p. was used from October, 1888 onwards, and with it speeds of from 10 to 70 m.p.h. were attained. The resources of the observatory were called upon, particularly with regard to chronographs, but the main pieces of apparatus were specially designed for the inquiry afoot. The possible errors due to circular motion of his test sections instead of a rectilinear one were dis-

cussed, and realised to be of a nature insusceptible of exact definition. Whilst ready to theorise wherever possible, Langley also clearly recognised the limitations of theoretical argument, an attitude which is still one of importance. Those of you who have taken an interest in the press accounts of Prof. Sherrington's address to the British Association will have seen how far lack of this power of discrimination can carry individuals. To read into the address on the relation between mind and certain parts of the brain, any idea that the working of the mind has been reduced to an understandable process would, I think, not occur to a scientist.

In carrying out his work, Langley was evidently troubled by the existence of a theory by Newton on the aerodynamic forces on an inclined surface. One can understand a state in which his experiments were discounted by others because they were at variance with Newton's sine-squared formula and the reaction indicated in the passage, "It is important to remember that the mathematical method as applied to physics, must always be trustworthy or untrustworthy, according to the trustworthiness of the data which are employed; that the most complete presentation of symbols and processes will only serve to enlarge the consequence of error hidden in the original premises, if such there be, and that here, as will be shown, the error as to fact begins with the great name of Newton himself."

Many defences of Newton have been attempted which reduce to the argument that his reasoning was faultless; that of course wholly fails to meet Langley's criticism; a little later we shall find an error of the same type in Langley's own deductions, and I for one prefer to accept them as they stand, examples of the limitations of the best of human beings. It is a comfort at times to be able to turn to the works of our great men and to find evidences of a frailty more marked in ourselves, but yet of the same character. It is an antidote to the oft-repeated saying that the last generation is better than the present. I suppose the saying was true at certain periods, the decline and fall of the Roman Empire, etc., and it may come to be really true here, but in all probability the remark generally only means a forgetting of the errors of the past, and a remembering of the better qualities. It is generous to the past, hardly just to the present.

The experiments devised by Langley are of a type not now used, and the deductions from them are rarely so direct as those made in an aerodynamics laboratory. This is partly due to the need for such experiments as could be made self-recording, direct observation at the end of a whirling arm not being feasible. Some first approximations to the measurement of lift and drag were made by the "suspended plane." This was a plate free to blow back under the influence of the wind about an axis through the upper edge. It was fairly heavy, two pounds, and so the angle taken up depended on the speed of the wind. The plate was suspended from its upper edge by a spring, the extension of which measured the force along the guides of the frame, *i.e.*, during an experiment gave the difference between the weight of the plane and the lift on it. Automatic records of the extension of this spring and the angle taken up by the plate at various speeds constituted the fundamental observations. In the reduction of them Langley appears to have assumed that, other things being the same, the aerodynamic reaction varied as the square of the speed, and that the pressure of a fluid is always normal to a surface moving in it. Neither of these is strictly true, the first ignoring the scale effect, first accurately indicated by the theorem of dynamical similarity, and put into form by the Lord Rayleigh; and the second being true only for a frictionless fluid. For the greater number of experiments made by Langley, the errors in the two assumptions would be small, but the second led to an important error at high speeds. Langley seems to have satisfied himself that the tangential component of the resultant force was negligible under all practical circumstances, and amongst the first to discover the error in this was Mr. F. W. Lanchester, who questioned the accuracy of the

statement by Langley that "a definite amount of power . . . will attain more economical results at high speeds than at low ones . . . up to some remote limit not yet attained in experiment but probably represented by higher speeds than have as yet been reached in any other mode of transport."

There is a caution attached to this remark as to a limit, but there is little doubt that Langley overestimated the advantages of high speed, and that the error was an error of deduction rather than observation. I have reproduced from Fig. 11 of his book on "Experiments in Aerodynamics," a diagram to illustrate this point. The ordinate of the curve is the resistance of an inclined plane of aspect ratio rather greater than 6, whilst the abscissæ are angles of incidence ranging up to 45 degrees. The plate weighed 500 grammes, and was moved round at "soaring speed" for each angle of incidence, *i.e.*, the lift on the plane was constant and equal to 500 grammes.

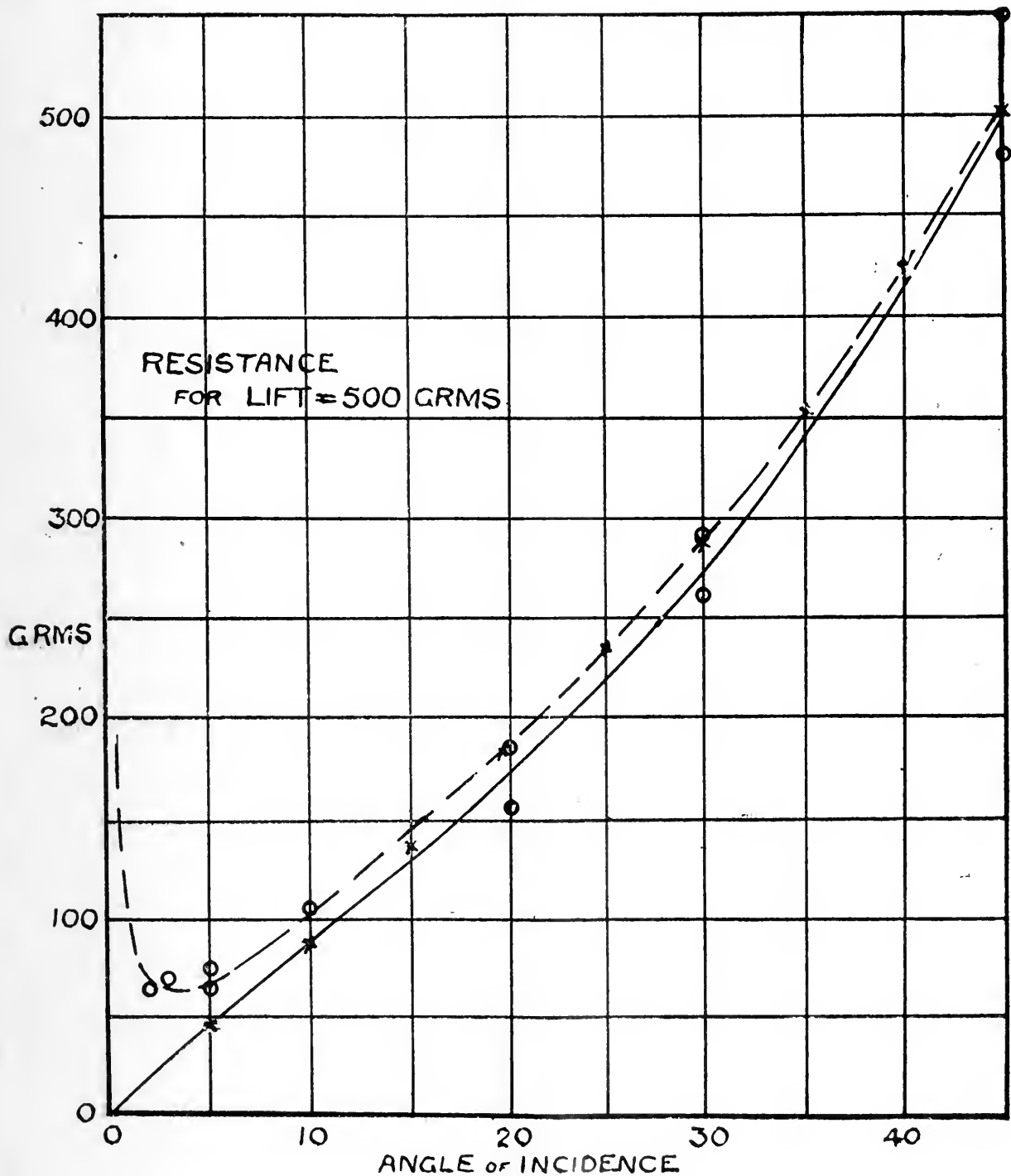


FIG. 1.

Observations are indicated by small circles, and a relatively high degree of accuracy is shown by the general consistency. Crosses were obtained by calculation on the hypothesis that the resultant force on the plane is normal to the surface, and it will be seen that at large angles of incidence the observed points lie close to the curve theoretically anticipated at that time. The proportionate discrepancy becomes important at angles of 5 to 10 degrees, and here Langley's trust in theory appears to have been great enough to mislead him. He says "For angles below 10 degrees, the curve (full line of figure), however, instead of following the measured pressure, is directed to the origin, so that the results will show a zero horizontal pressure for a zero angle of incidence. This, of course, must be the case for a plane of no thickness, and cannot be true for any planes of finite thickness with square edges, though it may be and is sensibly so with those whose edges are rounded to a so-called 'fair' form." In coming to this conclusion, Langley had made calculations of the normal force on the edge and the skin friction according to the then known formula, but as we now know, the conclusion was erroneous.

It led him to estimate the high value of 25 for the ratio of lift to drag of a plane at an angle of incidence of 2 degrees instead of a more probable 7 or 8. At angles greater than 10 degrees the error was not serious.

From the data given in his papers I have extracted sufficient to exhibit the results in diagrams of modern form. From Fig. 2 it will be seen that the curve of lift coefficient as a function of angle of incidence is of the normal form and that the maximum value of k_L of 0.4 agrees with more recent observations and indicates the general soundness of Langley's preliminary work. The curve for lift/drag is also of normal character, and in Fig. 2 observations are shown by circles. Langley's estimate corresponds closely with the theoretical assumption of zero skin friction, which leads to the highest curve of Fig. 2. At an angle of incidence of 5 degrees the estimate for lift/drag was not so high as 12, and we now know that values greater than this are utilisable with cambered planes of type fitted by Langley to his models.

Unfortunately, Langley stressed this point to one of extreme prominence in his work, and it has been commented on by critics ever since, rather to the exclusion of a fairer summary of the whole work. We find the following deduction from the above results:—"In this connection I may state the fact, surely of extreme interest in its bearing on the possibility of mechanical flight, that while an engine developing one horse-power can, as has been shown, transport over 200 pounds at a rate of 45 m.p.h., such an engine (i.e., engine and boiler) can be actually built to weigh less than one-tenth of this amount." This deduction is based on flight at 2 degrees and a lift to drag ratio of 25. In spite of his optimism, it may be seen that results which encouraged Langley to proceed would have reduced present-day designers to despair.

In his section on aerodynamics, other experiments of interest were made, some on the centre of pressure of a square plane, and also on its resistance in normal presentation.

In summarising his conclusions, Langley has matters of interest for us. For example, he says:—

"I am not prepared to say that the relations of power, area, weight, and speed, here experimentally established for planes of small area, will hold for indefinitely large ones; but from all the circumstances of experiment, I can entertain no doubt that they do so hold far enough to afford assurance that we can transport (with fuel for a considerable journey and at speeds high enough to make us independent of ordinary winds) weights many times greater than that of a man."

And again:—"I desire to add as a final caution, that I have not asserted that planes such as are here employed in experiment, or even that planes of

any kind, are the best forms to use in mechanical flight, and that I have also not asserted, without qualification, that mechanical flight is practically possible, since this involves questions as to the method of constructing the mechanism, of securing its safe ascent and descent, and also of securing the indispensable condition for the economic use of the power I have shown to be at our disposal—the condition, I mean, of our ability to guide it in the desired horizontal direction during transport—questions which, in my opinion, are only to be answered by further experiment, and which belong to the inchoate art or science of aerodromics, on which I do not enter.”

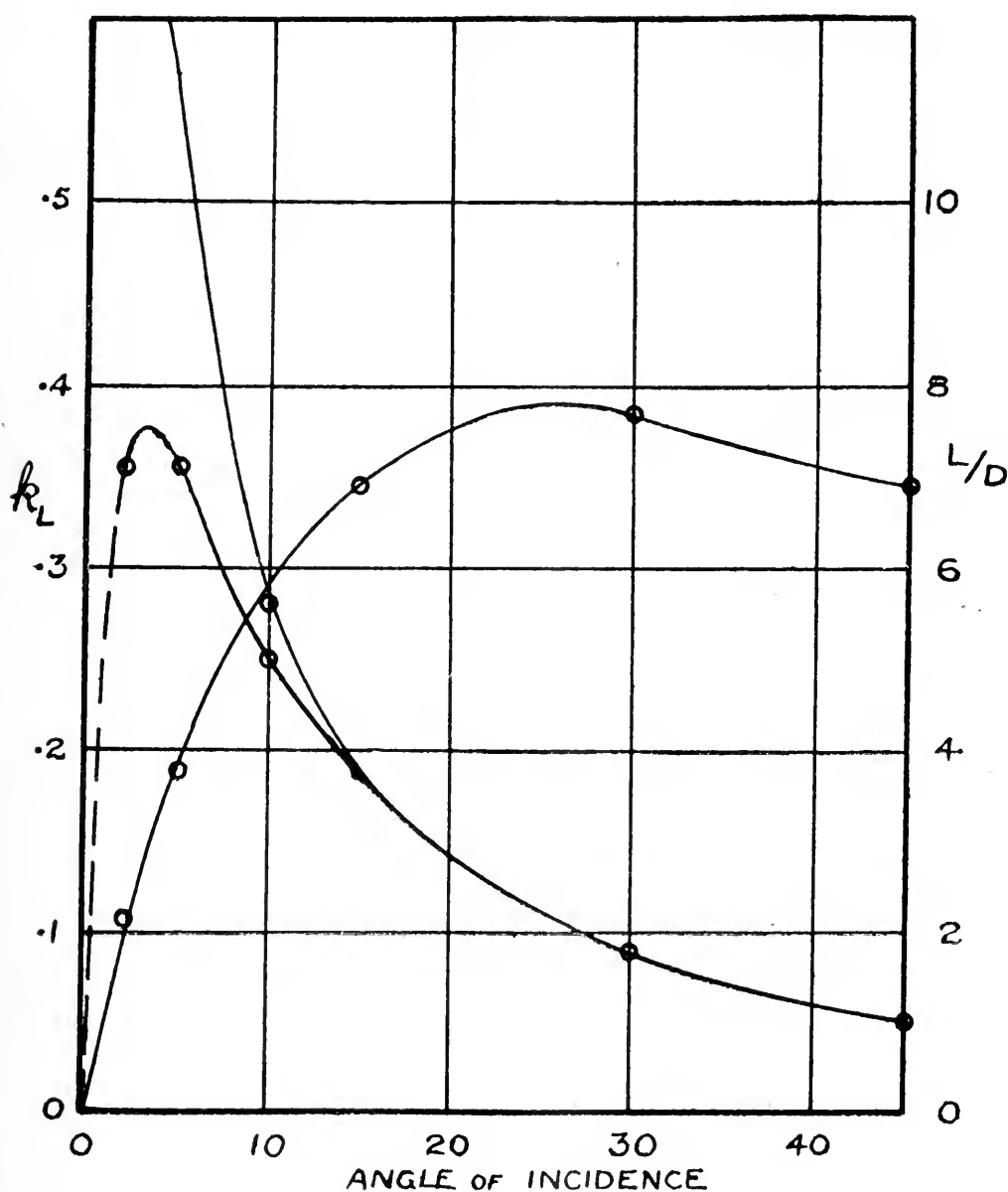


FIG. 2.

These remarks were made in 1891. They show a substantial, but not unblemished, record which was to serve as a basis for further work. Langley did indeed leave the subject of aerodynamics as he defined it, *i.e.*, performance in a secondary place whilst he attended to aerodromics or control and stability. He aimed at demonstrating the possibility of mechanical flight to a general public, and to him there was no noteworthy distinction between demonstration on a model or on a man-carrying aeroplane. In either case he thought that the aircraft ought to be capable of keeping itself in correct attitude in the air, and set himself to find the appropriate arrangements.

It is a long story, from which I propose to make extracts in due course, but in the end the demonstration was made. The model had two pairs of wings in tandem with a span of between 12 and 13ft., and an overall length of about 16ft. It weighed nearly 30lbs., of which about one-fourth was in the engine. The steam engine developed 1 to $1\frac{1}{2}$ h.p., and weighed only 26 ounces; it was fed by a boiler, which with its firegrate weighed a little over 5lbs. The wing area was 54 sq. ft., and the section had a camber of one in twelve.

As compared with the modern aeroplane the model was extremely lightly loaded (.55lbs. per sq. ft.) as against the more common present value of 7 or 8. The weight carried per h.p. was from 20 to 30lbs., a value very similar to that of bombing aircraft, or the fully-loaded civilian aeroplane. Langley's figures had not led him far wrong, for a reason that appears in one of the estimates of performance. Elements are reproduced below:—

Flying weight	...	...	...	...	22lbs.
Area of wings	...	...	...	...	40 sq. ft.
Engine power	...	...	...	...	1 h.p.
Power necessary to fly	...	...	...	...	0.35 h.p.
Flying speed for wings at 20 degrees	...	...	...	...	16-17 m.p.h.

As we saw a little time ago, 20 degrees is well inside the experimental range of the aerodynamic experiments and not liable to the error pointed to earlier. Further, Langley provided three times as much power as he estimated was necessary for flight, to cover inefficiency of gearing, airscrews, and errors in estimation. A number of minor flights were recorded, but the seal seems to have been set on May 6th and November 28th, 1896. Of them Mr. Manly says: "For the first* time in the history of the world a device produced by man had actually flown through the air, and had preserved its equilibrium without the aid of a guiding human intelligence. Not only had this device flown, but it had been given a second trial and had again flown, and had demonstrated that the result obtained in the first test was no mere accident."

On May 6th, 1896, Aerodrome No. 5 was launched directly into the gentle breeze which was then blowing. "The height of the launching track above the water was about 20ft. Immediately after leaving the launching track, the aerodrome slowly descended three or four feet, but immediately began to rise . . . to circle to the right, and moved around with great steadiness, traversing a spiral path as shown in the diagram.† During the first two turns the machine was constantly and steadily ascending, and at the end of the second turn it had reached a height variously estimated . . . at from 70 to 100ft. When at this height, and after a lapse of one minute and twenty seconds, the propellers were seen to be moving perceptibly slower, and the machine began to descend slowly. . . ." The distance traversed was a little over 3,000ft. at a rate of from 20 to 25 m.p.h. A second flight was made on the same day, which was also successful and a well earned reward of indomitable perseverance.

The record for November 28th, 1896, refers to Aerodrome No. 6, and the path is shown in the diagram. The flight extended for about three-quarters of a mile at a speed of approximately 30 m.p.h., and the success achieved led to the attempt of the next step, the making of a man-carrying aeroplane; the pilot was to be Mr. Manly. This stage had only been reached by much effort and care, and in the process ten years had gone. It was then that interest in

* This quotation is not in agreement with the records of aviation as found in the library of the Royal Aeronautical Society. In the chronology of "A Brief Account of the Aeronautical Society" will be found the reference—1848. Stringfellow succeeded in making his large model aeroplane to fly with a small steam engine. Further short flights appear in Hargraves' records of date 1884 or 1885.

† A number of slides were used to illustrate the lecture which are not reproduced here. In all cases the originals of the slides appeared in the Langley Memoir.

flying widened, slowly at first, but growing in strength until, less than twenty years after these model flights, the whole world was absorbed in the subject, and the records of airmen at the front thrilled every nation. We have gone back a little, let us hope to gather strength for the next forward move, but few now exist who envisage a return to the time when no aircraft existed. How much of this is due to Langley and his successful models? I don't suppose we can assess the relative value, but some of us at least feel that he bore the brunt of the fray for a long period without falling by the wayside, and so left us a legacy of example to be followed.

Before closing with a description of the man-carrying aeroplane—a description of qualified success, almost failure—a few words may be desirable on the early development. A number of slides, prepared from the figures in the "Langley Memoir," will perhaps help in making points clear.

"When the details of the aerodrome . . . are considered from the standpoint of the engineer accustomed to make every provision against breakage and accident, and to allow an ample factor of safety in every part, they will be found far too weak to stand the stresses that were put upon them. . . . It was absolutely necessary, in order to insure success, that the weight should be cut down to the lowest possible point, and when this was reached it was found that the factor of safety had been almost entirely done away with, and that the stresses applied and the strength were almost equal."

Of course this applied to steady flying, but now, after the expenditure of many millions of pounds in the development of military aircraft, the factor of safety against stunting is not so great as two.

"In the engine the three points aimed at in the design were lightness, strength and power, but lightness above all, and necessarily in a degree which long seemed incompatible with strength."

The steam was generated in a copper coil by the impinging on it of a flame from a burner working on the principle of the familiar blow lamp used by the plumber. The chamber *D* contained compressed air for forcing the gasoline from the tank *I* into the burner *N*. The flame played on the boiler coils *O* and the stack *Q* carried away the burnt gases. The steam passed from the boiler through a separator *M* before going to the engines. The latter are seen to be across the model (Pl. 29a), and were directly connected to the airscrew shafts. A synchronising shaft and bevel gears were fitted at the front of the frame.

In a note it is said "very exact accuracy in these minute details is indispensable to the efficient working of the engine." The power weights work out as follows :—

Engine	...	...	...	...	...	464 grammes
Pump and pump shafts	...	...	...	...	...	231 "
Gasoline tank and valves	...	...	...	...	...	178 "
Burners	...	...	...	...	...	360 "
Boilers, frames and mica covers	...	...	...	...	...	651 "
Separator, steam gauge and pipe	...	...	...	...	...	540 "
Exhaust pipe	...	...	...	...	...	143 "
Smoke stack	...	...	...	...	...	342 "

2,909 grammes or 6.4lbs.

In addition, the fuel at the beginning of the flight weighed 250 grammes and the water 2,350 grammes.

It is impossible for any one closely connected with the difficulties of experiment not to admire the skill with which so much detail was handled and the persistence which led to the passing of rock after rock in a new passage. Wrecks there were, but not a succession in the same place.

The photographic records of the flight are not so good as those of August 8th, 1903, on a quarter size model of the ill-fated man-carrying aeroplane.

On the subject of balancing the aerodrome, the memoir is interesting, and regards the problems in a different light from the present. "Equilibrium may be considered with reference to lateral or longitudinal stability. The lateral part is approximately secured with comparative ease, by imitating Nature's plans, and setting the wings at a dihedral angle, which I have usually made 150 degrees (15 degrees in present use of the term)." Langley then says: "I pass on to the far more difficult subject of longitudinal stability." After discussing the movement of centre of pressure and the effect of the position of the centre of gravity he concludes that, "These rules are purely empirical and only approximate. As approximations, they are useful in giving a preliminary balance, but the exact position is rarely determinable . . . except by experiment in actual flight."

I wonder how many of us, with all the data of the moment at our disposal, would be prepared to guarantee the first flight of a new aeroplane launched without pilot. Very few, I think, and those only optimists. In this respect we have a lot to learn, did the powers-that-be recognise the fact.

The Man-Carrying Aeroplane.

I propose to be very brief and to make my points mainly by reference to illustrations, which show the breadth of view of Langley and his colleagues. The experiments were made in a period when "his physician had counselled him that a resumption of concentrated thought and vigorous endeavour would materially shorten his life, which had already passed three score years." I wish that his further endeavour had received the crown of success given to his former efforts; it would have been a reward to him of the kind which he would have appreciated, but there will always be uncompleted tasks in a man's life history. He did a great deal and the little more would probably have made little difference to aviation, for the fires had been lighted and were beginning to burn freely. Only as a public acknowledgment do I wish that Manly and the Langley aerodrome had managed to fly for a mile or so during the trials of 1903. Instead, we find Manly attributing the end of Langley's experiments to the lack of immediate success and a consequential absence of financial support.

The outlines of the man-carrying glider are thus given:—"Starting with the assumption that Models Nos. 5 and 6 were capable of transporting a load of approximately 10 lbs. more than their weight, it was seen that, since the supporting surface of an aerodrome would increase approximately as the square of the linear dimensions, in order to carry a man the aerodrome would need to be approximately four times the linear dimensions of these models. Calculations based on the results accomplished in the construction of the models indicated that such an aerodrome would need to be equipped with engines developing 24 h.p. The best that could reasonably be hoped for was that these engines would not weigh over 200 lbs., and therefore, allowing 40 lbs. for fuel and fuel tanks, it became necessary to bring the weight of frame, supporting surfaces, tail, rudder, propellers, and every other accessory within 250 lbs. if the total weight of the machine, including 150 lbs. for the aeronaut, was not to exceed 640 lbs., or 16 times the combined weight of the model and its load of 10 lbs. Although the problem of constructing the frame, wings and all other parts within the limit of 250 lbs. seemed indeed formidable, it was believed that the greatest obstacle in the production of such a machine would be that of securing a sufficiently light and powerful engine to propel it."

In other respects, as in the balancing of the aeroplane, did Langley appreciate the difficulties, and his first intention was to fly with a dummy pilot in order to avoid possibly fatal consequences. The construction appears to have been begun in the summer of 1898, and the two unsuccessful attempts at flight occurred rather more than five years later in the autumn of 1903.

In order to give the large aeroplane the best opportunity, experiments were made on the flying of a model. "Before making the tests of the large aerodrome, it was intended to give the quarter-size model a preliminary trial to test the balancing which it was proposed to use on the large machine. . . for it was assumed that if the quarter-size model, which was an exact counterpart of the large machine, should fly successfully with the same balancing as that calculated for the larger one, the large one could reasonably be expected to act similarly." Photographs of the flights of this model were obtained on August 8th, 1903. In addition to these tests for balance, great care was exercised in the engineering design, Manly having been chosen expressly for his qualifications in this direction. The plates of details of the structure will show a result comparable with modern efforts. The results of experience preclude extension of this statement to the overall design, for in certain respects the type is far less effective for its purpose than the present biplane and small tail.

Two trials were attempted, and photographs are shown which indicate failures immediately after launching. In the earlier trial of October 7th, 1903, failure of the launching gear is definitely asserted; but in the second on December 8th, 1903, the early failure is very complete. Mr. Manly says, "The all-important question as to just what caused the accident which did occur remains to some extent a mystery." The structure is surmised to have failed at the end of the launching run by the loss of the tail and the crumpling of the rear wings. The aeroplane rose to the vertical and fell over backwards into the water.

This was the end of the series of experiments, for the Hammondsport trials were not part of the work of Langley, and in the opinion of many of us were ill-advised. The end did not come from lack of spirit, for "Doctor Langley considered it desirable to continue the experiments, but the Board deemed it advisable, largely in view of the adverse opinions expressed in Congress and elsewhere, to suspend operations in this direction." And again, "In the spring of 1904, after the repairs to the main frame were well under way, the writer (Mr. Manly), on his own initiative, undertook to see what could be done towards securing for Mr. Langley's disposal the small financial assistance necessary to continue the work; but he found that while a number of men of means were willing to assist in the development of the aerodrome, provided arrangements were made for later commercialisation, yet none were ready to render the assistance from a desire to assist in the prosecution of scientific work." On the other hand, Langley "had given his time and his best labours to the world without remuneration, and he could not bring himself at his stage of life to consent to capitalise his scientific work."

Is not this sketch rather an indication that Boards—including Air Ministries—cannot utilise the enthusiasm of scientists under their control? What is wrong? Is it the Air Ministry or the scientist, or both? Can an administrator who has no scientific knowledge direct the work of scientists? Has Britain ever allowed a fair trial to the executive control of scientific work by a man of science? How often have men of science been placed on advisory bodies and their advice ignored? I am not going to answer my own questions; in one aspect the ground is political and concerns our system of government, but in another it is a proper subject for the concern of a scientific and technical body like the Royal Aeronautical Society.

I have made my lecture rather long without covering the many interesting points in Langley's work in more than a sketchy manner. His speculations on soaring are worth the attention of any serious investigator who is trying to account for the phenomenal success of gliders.* I may not stay to deal with the subject now, for the digression, to be worth while, would be long.

* At the moment of revision of the proofs of this Paper it is interesting to note that the world's record for duration has just been obtained by M. Maneyrol on a glider having the tandem monoplane arrangement of wings characteristic of the Langley man-carrying aeroplane.

In conclusion, it appears to me that Langley belongs to the small band of pioneers who dared to attempt the seemingly impossible. Quite recently we have had a further attempt to climb Everest, an effort which is also dubbed failure. The climbing of 27,000 feet is not a matter for enthusiasm; the extra 2,000 feet would have been counted success, and yet I doubt the equity of the distinction. Surely the attempts which led to 27,000 feet and the examination of the limitations of human endurance are great contributions to the effort of that group of men who will one day stand on the summit of Everest! Surely Langley's place is of the same character as that of the climbers of Everest! He made it much easier for those to come; he helped the Wrights, the Bleriot and the Farman of the succeeding decade to reach the summit and to increase the time for which they could maintain themselves there. Such men as Langley are not to be expected frequently in the history of a nation; his example is not an easy one to follow. I have taken a great pleasure in preparing this account of his labours and in attempting to interest others in an understanding of the processes by which aviation has come. The lecture has been exclusively devoted to Langley without any desire to make or institute comparison with other pioneers. This is not for lack of appreciation but is due to limitations of time and space.

DISCUSSION.

Major WIMPERIS said he was sure they had all listened to Prof. Bairstow's lecture with very great interest. He had given them a record of indomitable perseverance, and that was a very welcome tonic. Moreover, the lecturer had not hesitated to lay bare certain—perhaps minor—points in which Langley really did go astray. It was a coincidence that their new President was also lecturer that evening, but he thought it was a happy coincidence, and the Council had decided to adopt that plan in the future—that the inaugural meeting of each new Session should be occupied by a lecture or paper by the incoming President. At some societies where that custom prevailed it was also the custom that the incoming President's words must be subjected to no form of criticism. That, however, was not the custom of the Royal Aeronautical Society, and he hoped that anybody in the audience who had any remarks to make of any sort or kind would not hesitate to make them.

Mr. BREWER said he would first like to draw attention to a phase in Langley's character which had only been touched upon very lightly by the lecturer, and that was the great courage which Langley showed in professing his belief in the possibility of mechanical flight at a time when anyone who professed that belief was regarded as a crank. Some of them could remember that time, and some of them had forgotten it. To show how strongly that feeling existed, he would point out that the United States Patent Office refuses at the present time to grant patents for perpetual motion, because they believed perpetual motion to be impossible. In Langley's day patents for flying machines were refused for the same reason, so they could imagine the courage that was required in a man who had already established his reputation in another field of science publicly to proclaim his belief in the possibility of flight and to devote the remainder of his life to proving that possibility. That was no small service that he did for aviation. He helped those who came after him by his example, and he would always be loved and remembered for it. There had been other prophets before Langley. There had been some Englishmen before who made models and prophesied. Henson, for instance, prophesied mechanical flight, and he made models as well. He made a model of a monoplane with two propellers to be driven by steam, but he accomplished no flights with these models as far as he (the speaker) was aware. Hargraves, in Australia, made power-driven models which flew before the time when Langley made his models fly. They were smaller than Langley's models, and they did not fly so far as Langley's models; but

still they were power-driven models driven by compressed air engines, and they were actually flying machines on a small scale. That, however, did not detract from the work of Langley because Langley's models were so much larger; but it did establish the fact that Langley's models were not the first power-driven models or the first power-driven mechanisms to fly. In the second paragraph of the lecture, Prof. Bairstow said:—"The end of this period—Langley's experiments from 1897 to 1903—is significant, coinciding almost precisely with the earliest successes of the Wright Brothers," and he would like to say a few words on that paragraph because Mr. Orville Wright was not present to reply to it. In what way could this period be significant, as stated by the lecturer? Prof. Bairstow told them that Prof. Langley published his work in two or three volumes. To be precise, Prof. Langley published a book which he entitled "Experiments in Aerodynamics" in 1891. His second book was a reprint of a paper read before the Aeronautical Congress at Chicago in 1893, and the third volume—a copy of which was on the table that evening—was the Langley Memoirs, published in 1911. Between 1893 and 1903, when the Wright Brothers flew, Langley published no data of his work. All his work was done quietly and, so far as he was aware, there was no publication of any of that work in that period of ten years. What was significant, then? Prof. Bairstow suggested that there was something significant in the Wrights flying ten years after these first two publications, and he could only imagine that the significance suggested was that the Wrights had obtained some information from Langley during the period when he was quietly trying his models and attempting to be the first to fly a full-size machine. He was strengthened in that reading of what Prof. Bairstow had said because he also stated that Langley helped the Wrights. So far as he personally knew, the Wrights obtained no information at all from Langley. The Wrights were entirely independent experimenters. They knew of the two earlier books of Langley, but there was nothing in their work which suggested that anything in these books had been of any value to them. He was very glad that Prof. Bairstow disowned the Hammondsport trials. The paper which he—the speaker—read before the Society last year on the Hammondsport trials involved a certain amount of risk. He had to show that high officials of the Smithsonian Institution had committed a fraud on the public. Two or three months ago he visited the Smithsonian Institution at Washington and saw the Langley machine hanging up with the same untrue label on it, saying that it was Langley's machine and that it had been flown at Hammondsport, and he was glad that Prof. Bairstow discountenanced those trials which were made in 1914. The attempt to prove that the Langley full-size machine of 1903 had been flown in the war period was untrue; the Langley machine had never been flown. Prof. Bairstow had stated in his Wilbur Wright lecture three years previously that the Langley machine had been flown in the war period, and he had good justification for making that statement, because it was based on the official report of the Smithsonian Institution. But that official report was untrue. As they knew, Prof. Langley was at one time secretary of the Smithsonian Institution, and Dr. Walcott was the present secretary.

Professor Bairstow had referred to the early flights of the Wright Brothers as secret flights. On the first day when the Wrights first flew into the air they sent invitations to everybody within six miles to see the flights. It was in December, and there were cold winds and nobody came. The lighthouse keeper and two or three other men in the actual locality came, so those first flights were not secret. Take the flights of the following year—in the early part of 1904 at Dayton. He knew the flying ground at Dayton because it was on the Wrights' flying ground that he was taught to fly. He took his ticket on the Wrights' ground at Dayton. A main road ran alongside down one boundary, a by-road adjoined another side of the field, the main railway which crosses the American Continent was within 200 yards, and electric cars ran between the railway and the main road. On the day when they were ready for their first flights

in 1904, the Wrights sent invitations to every newspaper to come and see the flights. Twelve or more representatives of newspapers were there, and about 50 other people also turned up. The engine would not work, and the flights for that day were a failure. No flight was made. The reporters came out the next day, but something else happened and no flights could be made. The reporters, although they said nothing, thought there was no use in coming out on further occasions. When the Wrights were flying for several minutes at a time the reporters heard of it, but they could not distinguish between airships and aeroplanes. In fact, they were all airships to the reporters, and they knew that Santos Dumont could fly for more than two or three minutes, and so they were very little interested. But he could not see how these flights could be regarded as secret flights with people passing in the trains and farmers on the other side of the hedge, and anyone could see them. Therefore it was unfair to describe the early flights of the Wright Brothers as secret flights.

At this point the CHAIRMAN asked Mr. Brewer to bring his remarks to a close as soon as possible owing to the lateness of the hour.

In conclusion, Mr. BREWER suggested that anyone who wished to follow up Langley's work should read two leading articles in "Nature"—one on November 3rd, 1921, and the other on January 26th, 1922, together with his (the speaker's) reply to those articles on March 9th this year. He had always imagined that Prof. Bairstow was the writer of those articles, and perhaps he would contradict him if he were wrong.

Prof. BAIRSTOW, replying to Mr. Brewer, said that the writing and preparation of the lecture was to some extent a consequence of the reading of Mr. Brewer's paper on the Hammondsport trials. He was also quite ready to remove any doubt there might be by saying that the "Nature" articles were written by himself. Unfortunately, Mr. Brewer and himself looked upon some of these points very differently. He would like to make it as clear as he possibly could that he regarded the Wright Brothers as the first flyers and the first producers of man-carrying aeroplanes. There was no doubt about it that Langley failed and failed after actual attempt at demonstration. He could not, however, go quite so far as Mr. Brewer did when he said the Wright Brothers received no assistance from Langley. He himself did not mean in papers, nor in curves, nor even his published books; but the fact that there was a man in their own country who professed belief—a belief to which Mr. Brewer himself had paid tribute—in the possibility of flying, and who had in 1896 demonstrated this by flying models, could not fail to place the Wrights under obligation to Langley. They must have received assistance from him in the sense which he had tried to indicate in the concluding remarks of the paper. It was not the data that Langley provided; it was the inspiration and his general idea, and he really believed that Mr. Brewer and himself were on common ground in this matter.

There was another point on which they differed a little also, although not seriously, and that was as to the secrecy of the flights made by the Wright Brothers. He himself was not specially interested in aviation in 1903. His interest arose when they heard of flights being carried out in France, and he remembered quite well that in the period between 1903 and 1908 it was so doubtful as to whether the Wrights had flown that many people in this country did not know of it at all. In fact, it was openly doubted here. Whether the flights ought to be described as secret or not was not a point which he desired to stress, but the fact was that very little was known of the Wright aeroplane until it was patented and had become a commercial proposition. That, he believed, was what Langley meant when he said the next stage was the commercial stage and was left for others. The Wright Brothers had done excellent work which he did not think detracted from Langley's.

The proceedings then closed.

HELICOPTERS.

BY JOHN CASE, M.A., F.R.Aë.S.

(Continued.)

PERFORMANCE CALCULATIONS.

17. At present, while we have but a vague conception of the form a practical helicopter is likely to take, it is useless to attempt to set out in detail the dynamics of helicopter flight or performance calculations. For the evolution of a practical machine of this type it seems to the author that it will be necessary first to study the stability equations neglecting everything but gravity and the screws themselves. This should show what stabilising surfaces are required, and it is with this object that the stability equations are given below. In the meanwhile it is perhaps worth while to obtain a broad view of the ground to be surveyed, and we must expect the work to be more complicated than in the case of the aeroplane.

For the present we shall suppose that there are no auxiliary tractor screws and that forward motion is obtained by inclining the axes of the supporting screws. In this case the centre of gravity of the whole machine is not fixed relative to the screws or body, which at once introduces complication to the equations of steady motion; the position of the centre of gravity will be a function of the inclination of the airscrew axes.

The properties of an aerofoil are completely determined by three absolute coefficients which are functions of a single variable, namely, the angle of incidence. Similarly, the properties of a helicopter screw can be defined by absolute coefficients, but they are six in number and each is a function of three variables. The six coefficients are those giving the forces along, and the couples about, three axes of reference; the independent variables are V/nD , the inclination of the axis to the direction of motion of the centre, and an angle defining the inclination of the blade sections to the plane of rotation. This last is not merely the pitch angle of the section, but the angle through which the blades are turned, voluntarily or automatically, since we must pre-suppose that the airscrews are of variable pitch:

With regard to the six coefficients, these may be taken as:—

- (i.) A force coefficient along the axis of the screw, denoted by k_T .
- (ii.) A force coefficient parallel to the axis of z (Fig. 11).
- (iii.) A force coefficient parallel to the axis of y (Fig. 11); this is zero.
- (iv.) A torque coefficient (k_Q) about the axis of the screw.
- (v.) A coefficient defining the mean distance of the line of action of the force Z (§ 10) from the centre of the screw.
- (vi.) A similar coefficient for the force Y , and this is zero.

Thus the number of coefficients required completely to define the properties of the screws reduces to four. In place of (i.) and (ii.) above we may take coefficients of forces along and normal to the flight path, *i.e.*, to the direction of the relative wind. It must remain to be seen which procedure is the more convenient.

For each position of the blades of a variable pitch screw, or for each screw of fixed pitch, each of these coefficients will be presented as a family of curves plotted on a base of V/nD , each member of the family corresponding with a given inclination of the axis of the screw.

18. For climbing vertically we can, from the data of the screws and the drawings of the machine, prepare curves such as shown in Fig. 17. From these

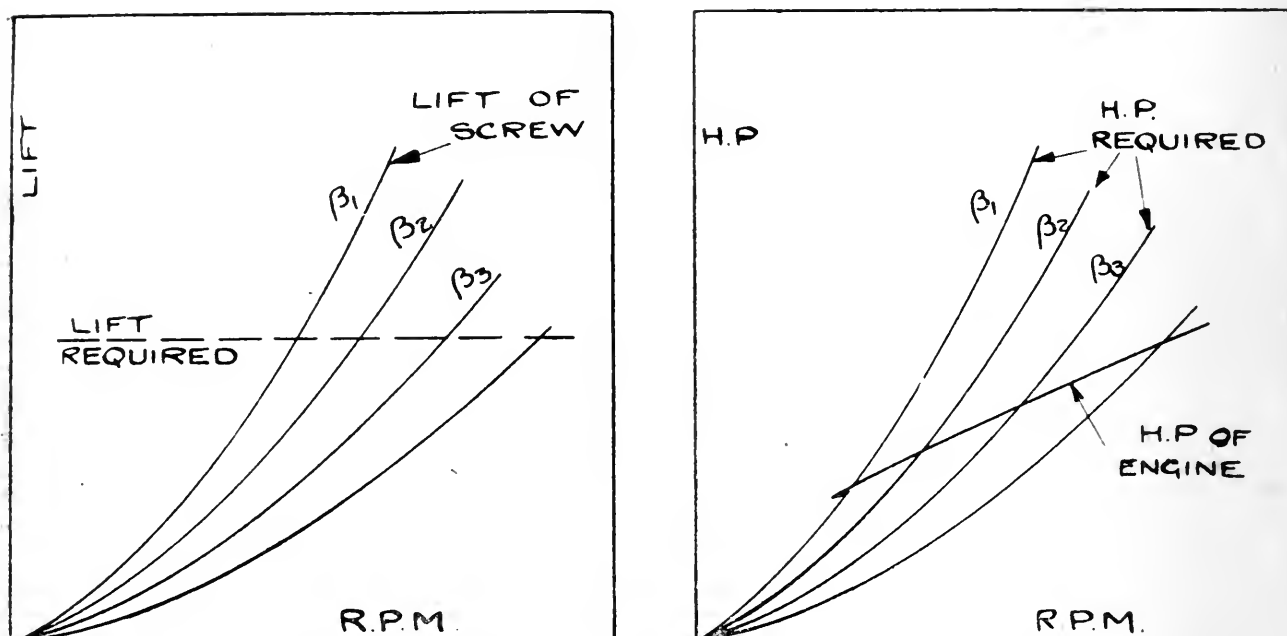


FIG. 17.

we can obtain the maximum rate of climb for a given weight, and the maximum weight for a given rate of climb, etc.

19. For climbing in an inclined path the conditions are more complicated, since more variables are introduced. In order to be consistent with the system of axes chosen for forming the stability equations, we shall suppose the axis of x to be in the direction of motion, *i.e.*, through the c.g. of the whole machine and tangential to the flight path; the axis of z is along the normal to the flight path (see Fig. 18).

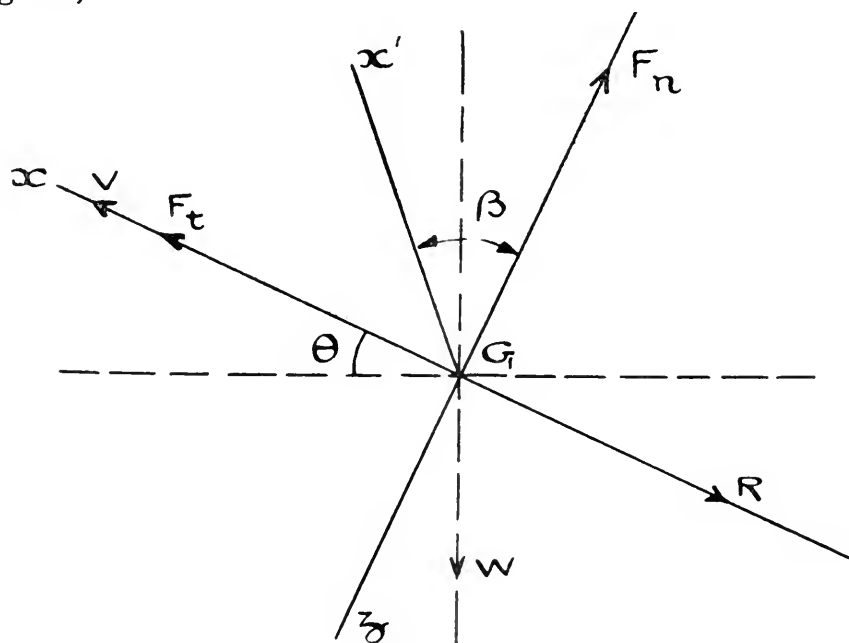


FIG. 18.

In Fig. 18, Gx' is the axis of the airscrew* and Gx is the direction of motion.

* Or the line of action of the resultant thrust if there be several airscrews.

Let F_n and F_t be the forces along the tangent and normal to the flight path. Then let

$$F_n = \rho n^2 D^4 k_n = \rho n^2 D^4 f_n (V/nD, \beta)$$

$$F_t = \rho n^2 D^4 k_t = \rho n^2 D^4 f_t (V/nD, \beta)$$

Then k_n and k_t correspond with k_L and k_D for an aerofoil and are functions of V/nD and β .

Let R be the resistance of the whole of the machine minus the screws.

Then in steady motion we must have:—

$$F_n = W \cos \theta \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$F_t - R = W \sin \theta \quad . \quad . \quad . \quad . \quad . \quad (17)$$

For given values of β we can draw curves of F_n and F_t against V for various values of n . We can also draw curves of R against V for different values of θ , as in Fig. 19.

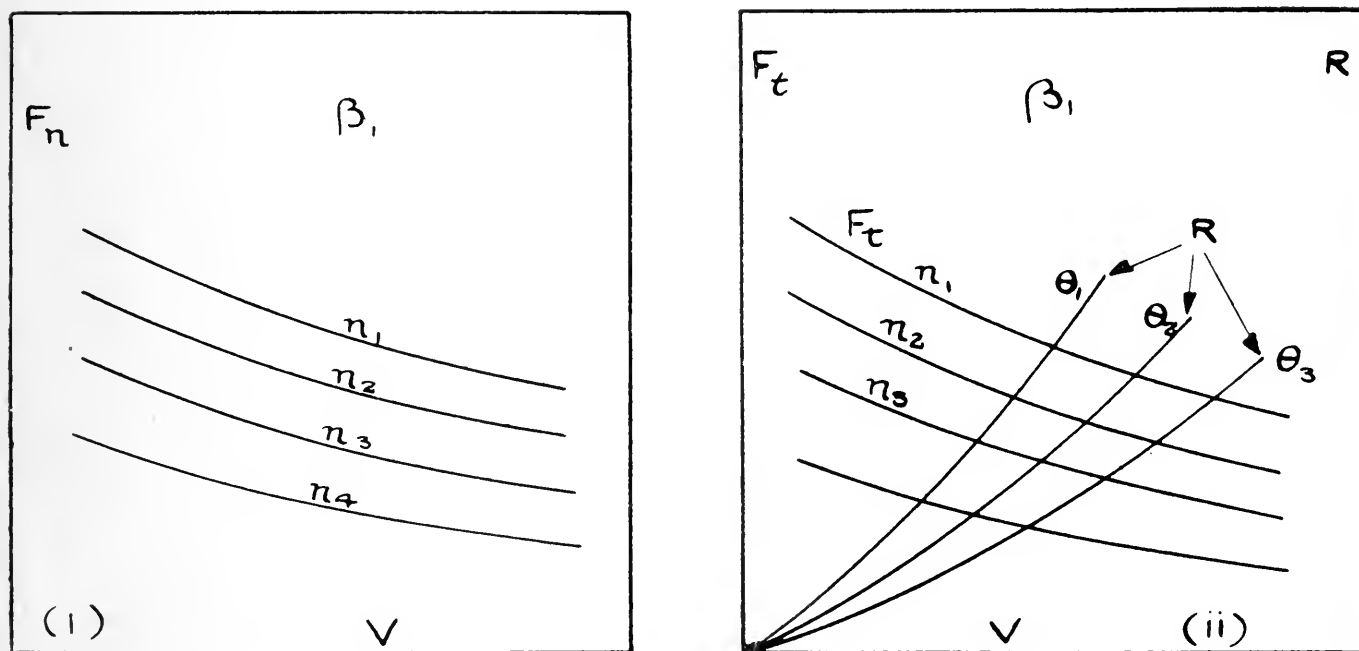


FIG. 19.

Then, taking an arbitrary value of θ , we find from Fig. 19 (i.) an infinite number of pairs of values of n and V which satisfy equation (16), and by Fig. 19 (ii.) we can test if equation (17) is satisfied; by a succession of trials we find values of V , n and θ , which satisfy both equations (16) and (17). By this means we can draw curves of V against θ for various values of n . This process can be repeated for successive values of β . Finally taking into consideration the power required by the screws and the power available, we can draw curves of the maximum V possible, for different values of β , on a base of θ .

These remarks should be sufficient to indicate the nature of the calculations which will be involved, but, as we have remarked above, it would not be profitable to go into any greater detail at the present stage.

STABILITY.

20. A complete general treatment of the problem of helicopter stability is hardly possible with our present knowledge of the properties of airscrews moving with large sideslip velocities, but it is hoped that the following notes will be of interest and that they will be sufficient to indicate the lines along which the work must proceed. The equations given below should be sufficient for the examina-

tion of the stability when the motion is nearly vertical, ascending or descending with or without the engines, besides showing the nature of the general stability equation.

In what follows we shall limit ourselves to the consideration of rectilinear motion, and from the equations given here it will be easy to write down by analogy the equations for curvilinear motion.

Except where stated otherwise the notation is the standard stability notation as used for aeroplanes.

21. Axes.

The origin is at the centre of gravity G of the helicopter and the axes are fixed in the machine, which we assume to have at least one plane of symmetry. The axis of x is in the direction of the undisturbed motion; the axis of z is in the plane of symmetry, perpendicular to the axis of x , and in such a direction that when Gx is horizontal Gz is downwards; the axis of y is perpendicular to Gx and Gz and forms with them a system of right-handed axes. The axis of x makes an angle θ_0 with the horizon in the undisturbed motion, and the velocity of the machine in the direction Gx is V .

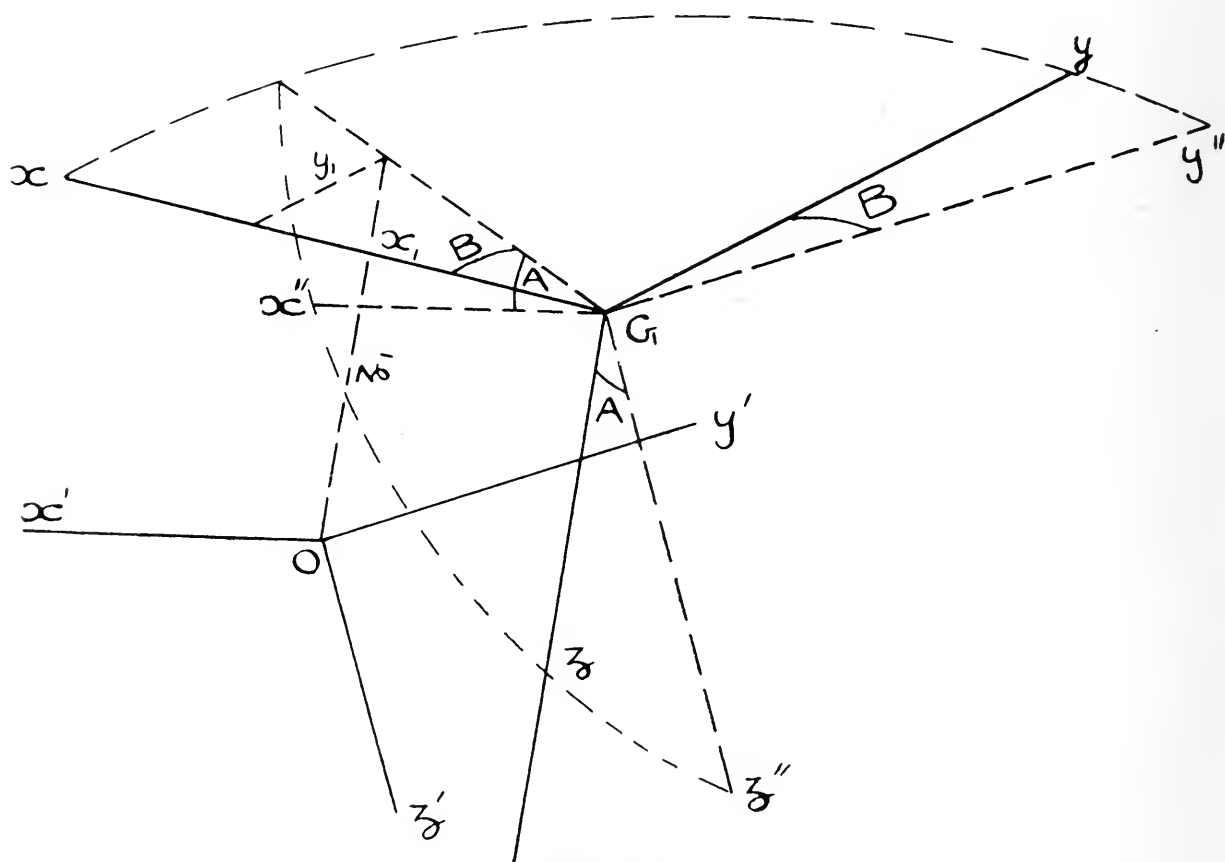


FIG. 20.

A second system of axes has its origin at O , the centre of one of the screws, and the co-ordinates of O referred to G are (x_1, y_1, z_1) . Ox' is the axis of the screw; it makes an angle A with the plane xGy and lies in a plane making an angle B with the plane xGz . Usually z_1 and A will be negative.

With the hope of making clear the relationship of the two systems a third set of axes, Gx'' , Gy'' , Gz'' , is shown dotted; these are parallel to Ox' , Oy' , Oz' , respectively.

All forces, moments, velocities and derivatives when referred to the helicopter axes ($Gxyz$) will be denoted by unaccented letters; when referred to the airscrew axes ($Ox'y'z'$) they will be denoted by the corresponding accented letters.

22. Relations Between the Two Systems of Axes.

If u, v, w, p, q, r denote velocities referred to the helicopter axes the corresponding velocities referred to the airscrew axes are:—

$$\left. \begin{aligned} u' &= +\bar{u} \cos A \cos B + \bar{v} \cos A \sin B + \bar{w} \sin A \\ v' &= -\bar{u} \sin B + v \cos B \\ w' &= -\bar{u} \sin A \cos B - \bar{v} \sin A \sin B + \bar{w} \cos A \\ p' &= p \cos A \cos B + q \cos A \sin B + r \sin A \\ q' &= -p \sin B + q \cos B \\ r' &= -p \sin A \cos B - q \sin A \sin B + r \cos A \end{aligned} \right\} \quad (20)$$

where

$$\left. \begin{aligned} \bar{u} &= u - y_1 r + z_1 q \dots \\ \bar{v} &= v - z_1 p + x_1 r \dots \\ \bar{w} &= w - x_1 q + y_1 p \dots \end{aligned} \right\} \quad (21)$$

Again, if mX, mY, mZ, L, M, N , are the forces and couples referred to the helicopter axes, and accented letters refer to the airscrew axes, we have

$$\left\{ \begin{aligned} X &= X' \cos A \cos B - Y' \sin B - Z' \sin A \cos B \\ Y &= X' \cos A \sin B + Y' \cos B - Z' \sin A \sin B \\ Z &= X' \sin A + Z' \cos A \\ L &= L' \cos A \cos B - M' \sin B - N' \sin A + mZy_1 - mYz_1 \\ M &= L' \cos A \sin B + M' \cos B + mXz_1 - mZx_1 \\ N &= L' \sin A + N' \cos A + mYx_1 - mXy_1 \end{aligned} \right\} \quad (22)$$

23. The Torque Equation.

In general the forces and couples acting on the helicopter will depend on the speed of rotation of the screws as well as the six velocity components, u, v, w, p, q, r , so that there will be resistance derivatives with respect to seven variables instead of six. It will also be necessary to introduce the torque equation for the screws. Thus, the general stability equation will be a seven-row determinant equated to zero.

The extra equation is found as follows:—

Let I = the moment of inertia of a screw.

Q'_a = the torque on the airscrew due to the air reactions.

Q_e = the driving torque due to the engine.

n = the speed of rotation of the screw.

Then, denoting the derivatives by suffixes in the usual way, the equation for the screw is:—

$$\begin{aligned} -2\pi I \dot{n} &= Q'_{au} u' + Q'_{av} v' + Q'_{aw} w' + Q'_{ap} p' + Q'_{aq} q' + Q'_{ar} r' \\ &\quad + (Q'_{an} - Q_{en}) n \end{aligned} \quad (18)$$

or it may be written

$$\begin{aligned} -2\pi I \dot{n} &= Q_{au} u + Q_{av} v + Q_{aw} w + Q_{ap} p + Q_{aq} q + Q_{ar} r \\ &\quad + (Q_{an} - Q_{en}) n \end{aligned} \quad (18a)$$

24. Stability Equation.

Postponing for the present the evaluation of the derivatives, we can now write down the general stability equation:—

$$\begin{vmatrix}
 X_u - \lambda & X_v & X_w & X_p & \lambda X_q - g \cos \theta_0 & X_r & X_n \\
 Y_u & Y_v - \lambda & Y_w & \lambda Y_p + g \cos \theta_0 & Y_q & \lambda (Y_r - V) + g \sin \theta_0 & Y_n \\
 Z_u & Z_v & Z_w - \lambda & Z_p & \lambda (V + Z_q) - g \sin \theta_0 & Z_r & Z_n \\
 L_u & L_v & L_w & \lambda L_p - A\lambda^2 & L_q & \lambda L_r + E\lambda^2 & L_n \\
 M_u & M_v & M_w & M_p & \lambda M_q - B\lambda^2 & M_r & M_n \\
 N_u & N_v & N_w & \lambda N_p + E\lambda^2 & N_q & \lambda N_r - C\lambda^2 & N_n \\
 Q_{au} & Q_{av} & Q_{aw} & Q_{ap} & Q_{aq} & Q_{ar} & 2\pi I\lambda + Q_{an} - Q_{en}
 \end{vmatrix} = 0 \quad (19)$$

This is the general equation for the stability of the motion of a helicopter in a straight line; it will be seen to be of the tenth degree. The equation for curvilinear motion can be written down at once by comparing this with equation (72) on p. 490 of Bairstow's "Applied Aerodynamics."

The derivatives will have contributions from each of the screws and from the rest of the machine, and these must be added together. We shall confine our attention here to those parts of the derivatives which are due to the screws.

We have not attempted the expansion of the above determinant as it seems that no good purpose would be served by it at present; we shall see instead what simplifications can be made in special cases.

25. Formation of the Derivatives.

When the direction of motion makes a small angle with the axis of the screw the derivatives can be calculated by the formulæ given by H. Glauert in R. and M. 642 and reproduced here in Table VI., but at present we have no formulæ for their evaluation when the angle between the direction of motion and the axis of the screw is large. Perhaps we might derive formulæ for this case by Mr. Glauert's method, but it seems likely that it will be necessary to do a considerable amount of work in the wind tunnel before we can satisfactorily study the general stability of a helicopter. This means that for the present we are limited to motion which is nearly vertical.

26. Expressions for the Derivatives.

Consider as an example the X derivatives. If there be a disturbance denoted by $(u, v \dots r)$ referred to the helicopter axes or $(u', v' \dots r')$ referred to the airscrew axes, the change effected in X is given by

$$dX = dX' \cos A \cos B - dY' \sin B - dZ' \sin A \cos B \quad (23)$$

by (22). Now

$$dX' = X'_u u' + X'_v v' + \dots + X'_r r' \quad (24)$$

with similar expressions for dY' and dZ' .

We can substitute for $u', v' \dots r'$ in terms of $u, v \dots r$ by means of (20) and (21), thus expressing dX', dY' and dZ' in terms of $X'_u \dots X'_r$ and $u' \dots r'$. We then substitute in (23) and the result is of the form

$$dX = f(X'_u \dots X'_r; Y'_u \dots Y'_r; Z'_u \dots Z'_r; u, v \dots r).$$

Then X_u is the coefficient of u in this expression, and so on.

By this means the derivatives for the helicopter are expressed in terms of those for the screw. Formulæ for calculating the latter, when the velocity of sideslip is small compared with the velocity along the axis of the screw, are given below in Table VI.

TABLE VI.

Airscrew derivatives referred to axes through centre of airscrew (Glauert in R. and M. 642).

	u	v	w	p	q	r
mX'	$\frac{2T}{V} \cdot \frac{\lambda_T(1+\lambda_P) - \lambda_Q}{1+\lambda_P - \lambda_Q}$	0	0	$\frac{DTJ}{\pi V} \cdot \frac{\lambda_P(1-\lambda_T)}{1+\lambda_P - \lambda_Q}$	0	0
mY'	0	$-\frac{k_1 QJ(1-\lambda_Q)^*}{2\pi V D}$	$\frac{k_1 QJ(1-\lambda_Q)^\dagger}{2\pi V D}$	0	$\frac{Q}{V} \lambda_Q^*$	$-\frac{Q}{V} \lambda_Q^\dagger$
mZ'	0	$\frac{k_1 QJ(1-\lambda_Q)^\dagger}{2\pi V D}$	$-\frac{k_1 QJ(1-\lambda_Q)^\S}{2\pi V D}$	0	$-\frac{Q}{V} \lambda_Q^\dagger$	$\frac{Q}{V} \lambda_Q^\S$
I'	$-\frac{2Q}{V} \cdot \frac{\lambda_P \lambda_Q}{1+\lambda_P - \lambda_Q}$	0	0	$-\frac{DQJ}{\pi V} \cdot \frac{\lambda_P(1-\lambda_Q)}{1+\lambda_P - \lambda_Q}$	0	0
M'	0	$-\frac{DTJ}{2\pi V} (1-\lambda_T)^*$	$\frac{DTJ(1-\lambda_T)^\dagger}{2\pi V}$	0	$k_2 D^2 \frac{T}{V} \lambda_T^*$	$-k_2 D^2 \frac{T}{V} \lambda_T^\dagger$
N'	0	$\frac{DTJ(1-\lambda_T)^\dagger}{2\pi V}$	$-\frac{DTJ(1-\lambda_T)^\S}{2\pi V}$	0	$-k_2 D^2 \frac{T}{V} \lambda_T^\dagger$	$k_2 D^2 \frac{T}{V} \lambda_T^\S$

When the propeller has only two blades, expressions marked * must be multiplied by $(1 - \cos 2\pi nt)$, those marked † by $\sin 2\pi nt$, and those marked § by $(1 + \cos 2\pi nt)$.

When there are more than two blades the terms marked † are zero.

The above refer to a right-handed screw; for a left-handed screw the sign of the following must be changed:—

$$\begin{aligned} \text{Also } \lambda_T &= \frac{1}{2} \frac{J}{k_T} \cdot \frac{dk_T}{dJ} & Y'_w Z'_v L'_u M'_v N'_w \\ & & X'_p Y'_q Z'_r M'_r N'_q \\ \lambda_Q &= \frac{1}{2} \frac{J}{k_Q} \cdot \frac{dk_Q}{dJ} & k_1 \text{ may be taken as } 14.4 \\ & & k_2 \text{ " " " } 0.10 \\ & & 2\lambda_P = 1 - \frac{n}{P} \cdot \frac{dP}{dn} \text{ where } P \text{ is the power of the engine.} \end{aligned}$$

It will be seen that in this case many of the derivatives referred to the air-screw axis disappear, which results in a corresponding simplification of the equations.

The derivatives for the screw referred to the main axes are in this case:—

$$X_u = X'_u \cos^2 A \cos^2 B + Y'_v \sin^2 B + Y'_w \sin A \sin B \cos B + Z'_v \sin A \sin B \cos B + Z'_w \sin^2 A \cos^2 B.$$

$$X_v = X'_u \cos^2 A \sin B \cos B - Y'_v \sin B \cos B + Y'_w \sin A \sin^2 B - Z'_v \sin A \cos^2 B + Z'_w \sin^2 A \sin B \cos B.$$

$$X_w = X'_u \sin A \cos A \cos B - Y'_w \cos A \sin B - Z'_w \sin A \cos A \cos B.$$

$$X_p = X'_u (y_1 \sin A - z_1 \cos A \sin B) \cos A \cos B + X'_p \cos^2 A \cos^2 B.$$

$$+ Y'_v z_1 \cos B \sin B - Y'_w (y_1 \cos A + z_1 \sin A \sin B) \sin B.$$

$$+ Y'_q \sin^2 B + Y'_r \sin A \sin B \cos B.$$

$$+ Z'_v z_1 \sin A \cos^2 B - Z'_w (y_1 \cos A + z_1 \sin A \sin B) \sin A \cos B.$$

$$- Z'_q \sin A \sin B \cos B + Z'_r \sin^2 A \cos^2 B.$$

$$X_q = X'_u (z_1 \cos A \cos B - x_1 \sin A) \cos A \cos B + X'_p \cos^2 A \sin B \cos B.$$

$$+ Y'_v z_1 \sin^2 B + Y'_w (z_1 \sin A \cos B + x_1 \cos A) \sin B.$$

$$+ Y'_q \sin B \cos B - Y'_r \sin A \sin^2 B + Z'_v z_1 \sin A \sin B \cos B.$$

$$+ Z'_w (z_1 \sin A \cos B + x_1 \cos A) \sin A \cos B - Z'_q \sin A \cos^2 B.$$

$$+ Z'_r \sin^2 A \sin B \cos B.$$

$$X_r = X'_u (x_1 \sin B - y_1 \cos B) \cos^2 A \cos B + X'_p \sin A \cos A \cos B.$$

$$- Y'_v (x_1 \cos B + y_1 \sin B) \sin B - Y'_w (x_1 \sin B - y_1 \cos B) \sin A \sin B.$$

$$+ Y'_r \cos A \sin B - Z'_v (x_1 \cos B + y_1 \sin B) \sin A \cos B.$$

$$+ Z'_w (x_1 \sin B - y_1 \cos B) \sin^2 A \cos B - Z'_r \sin A \cos A \cos B.$$

$$Y_u = X'_u \cos^2 A \sin B \cos B - Y'_v \sin B \cos B - Y'_w \sin A \cos^2 B + Z'_v \sin A \sin^2 B + Z'_w \sin^2 A \sin B \cos B.$$

$$Y_v = X'_u \cos^2 A \sin^2 B + Y'_v \cos^2 B - Y'_w \sin A \sin B \cos B - Z'_v \sin A \sin B \cos B + Z'_w \sin^2 A \sin^2 B.$$

$$Y_w = X'_u \sin A \cos A \sin B + Y'_w \cos A \cos B - Z'_w \sin A \cos A \sin B.$$

$$Y_p = -X'_u (z_1 \cos A \sin B - y_1 \sin A) \cos A \sin B.$$

$$+ X'_p \cos^2 A \sin B \cos B - Y'_v z_1 \cos^2 B.$$

$$+ Y'_w (y_1 \cos A + z_1 \sin A \sin B) \cos B - Y'_q \sin B \cos B.$$

$$- Y'_r \sin A \cos^2 B - Z'_w (y_1 \cos A + z_1 \sin A \sin B) \sin A \sin B.$$

$$+ Z'_q \sin A \sin^2 B + Z'_r \sin^2 A \sin B \cos B + Z'_v z_1 \sin A \sin B \cos B.$$

$$Y_q = X'_u (z_1 \cos A \cos B - x_1 \sin A) \cos A \sin B.$$

$$+ X'_p \cos^2 A \sin^2 B - Y'_v z_1 \sin B \cos B.$$

$$- Y'_w (z_1 \sin A \cos B + x_1 \cos A) \cos B + Y'_q \cos^2 B.$$

$$- Y'_r \sin A \cos^2 B + Z'_v z_1 \sin A \sin^2 B.$$

$$+ Z'_w (z_1 \sin A \cos B + x_1 \cos A) \sin A \sin B - Z'_q \sin A \sin B \cos B.$$

$$+ Z'_r \sin^2 A \sin B \cos B.$$

$$Y_r = X'_u (x_1 \sin B - y_1 \cos B) \cos^2 A \sin B + X'_p \sin A \cos A \sin B.$$

$$+ Y'_v (x_1 \cos B + y_1 \sin B) \cos B.$$

$$- Y'_w (x_1 \sin B - y_1 \cos B) \sin A \cos B + Y'_r \cos A \cos B.$$

$$- Z'_v (x_1 \cos B + y_1 \sin B) \sin A \sin B + Z'_w (x_1 \sin B - y_1 \cos B) \sin^2 A \sin B.$$

$$- Z'_r \sin A \cos A \sin B.$$

$$Z_u = X'_u \sin A \cos A \cos B - Z'_v \cos A \sin B - Z'_w \sin A \cos A \cos B.$$

$$Z_v = X'_u \sin A \cos A \sin B + Z'_v \cos A \cos B - Z'_w \sin A \cos A \sin B.$$

$$Z_w = X'_u \sin^2 A + Z'_w \cos^2 A.$$

$$Z_p = -X'_u (z_1 \cos A \sin B - y_1 \sin A) \sin A + X'_p \sin A \cos A \cos B.$$

$$- Z'_v z_1 \cos A \cos B + Z'_w (y_1 \cos A + z_1 \sin A \sin B) \cos A.$$

$$- Z'_q \cos A \sin B - Z'_r \sin A \cos A \cos B.$$

$$Z_q = X'_u (z_1 \cos A \cos B - x_1 \sin A) \sin A + X'_p \sin A \cos A \sin B.$$

$$- Z'_v z_1 \cos A \sin B - Z'_w (z_1 \sin A \cos B + x_1 \cos A) \cos A.$$

$$+ Z'_q \cos A \cos B - Z'_r \sin A \cos A \sin B.$$

$$Z_r = X'_u (x_1 \sin B - y_1 \cos B) \sin A \cos A + X'_p \sin^2 A.$$

$$+ Z'_v (y_1 \sin B + x_1 \cos B) \cos A.$$

$$- Z'_w (x_1 \sin B - y_1 \cos B) \sin A \cos A + Z'_r \cos^2 A.$$

$$\begin{aligned}
L_u &= + mX'_u (y_1 \sin A - z_1 \cos A \sin B) \cos A \cos B. \\
&\quad - mY'_v z_1 \cos B \sin B - mY'_w z_1 \sin A \cos^2 B. \\
&\quad - mZ'_v y_1 \sin A \sin B - mZ'_w y_1 \sin^2 A \cos B + L'_u \cos^2 A \cos^2 B. \\
&\quad + M'_v \sin^2 B + M'_w \sin A \sin B \cos B + N'_v \sin A \sin B. \\
&\quad + N'_w \sin^2 A \cos B. \\
L_v &= + mX'_u (y_1 \sin A - z_1 \cos A \sin B) \cos A \sin B. \\
&\quad + mY'_v z_1 \cos^2 B - mY'_w z_1 \sin A \sin B \cos B. \\
&\quad + mZ'_v y_1 \sin A \cos B - mZ'_w y_1 \sin^2 A \sin B. \\
&\quad + L'_u \cos^2 A \sin B \cos B - M'_v \sin B \cos B + M'_w \sin A \sin^2 B. \\
&\quad - N'_v \sin A \cos B + N'_w \sin^2 A \sin B. \\
L_w &= mX'_u (y_1 \sin A - z_1 \cos A \sin B) \sin A. \\
&\quad + mY'_w (z_1 \cos B) \cos A + mZ'_w y_1 \sin A \cos A. \\
&\quad + L'_u \sin A \cos A \cos B - M'_w \cos A \sin B - N'_w \sin A \cos A. \\
I_{vp} &= mX'_u (-z_1 \cos A \sin B + y_1 \sin A)^2 \cos A. \\
&\quad + mX'_p (y_1 \sin A - z_1 \sin B \cos A) \cos A \cos B. \\
&\quad - mY'_v z_1^2 \cos^2 B. \\
&\quad + mY'_w (z_1 \cos B) (z_1 \sin A \sin B + y_1 \cos A). \\
&\quad - mY'_q z_1 \cos B \sin B - mY'_r z_1 \cos B \sin A \cos B. \\
&\quad - mZ'_v y_1 z_1 \sin A \cos B + mZ'_w y_1 \sin A (z_1 \sin A \sin B + y_1 \cos A). \\
&\quad - mZ'_q y_1 \sin A \sin B - mZ'_r \sin^2 A \cos B. \\
&\quad + L'_u (-z_1 \cos A \sin B + y_1 \sin A) \cos A \cos B + L'_p \cos^2 A \cos^2 B. \\
&\quad + M'_v z_1 \sin B \cos B - M'_w (z_1 \sin A \sin B + y_1 \cos A) \sin B. \\
&\quad + M'_q \sin^2 B + M'_r \sin A \sin B \cos B + N'_v z_1 \sin A \cos B. \\
&\quad - N'_w (z_1 \sin A \sin B + y_1 \cos A) \sin A + N'_q \sin A \sin B. \\
&\quad + N'_r \sin^2 A \cos B. \\
L_q &= + mX'_u (y_1 \sin A - z_1 \cos A \sin B) (z_1 \cos A \sin B - x_1 \sin A). \\
&\quad + mX'_p (\sin A - z_1 \cos A \sin B) \cos A \sin B. \\
&\quad - mY'_v z_1^2 \cos B \sin B. \\
&\quad - mY'_w (z_1 \cos B) (z_1 \sin A \cos B + x_1 \cos A). \\
&\quad - mY'_q z_1 \cos^2 B - mY'_r z_1 \cos B \sin A \sin B. \\
&\quad - mZ'_v y_1 z_1 \sin A \sin B - mZ'_w y_1 \sin A (z_1 \sin A \cos B + x_1 \cos A). \\
&\quad + mZ'_q y_1 \sin A \cos B - mZ'_r y_1 \sin^2 A \sin B. \\
&\quad + L'_u (z_1 \cos A \sin B - x_1 \sin A) \cos A \cos B + L'_p \cos^2 A \sin B \cos B. \\
&\quad + M'_v z_1 \sin^2 B + M'_w (z_1 \sin A \cos B + x_1 \cos A) \sin B. \\
&\quad - M'_q \sin B \cos B + M'_r \sin A \sin^2 B + N'_v z_1 \sin A \sin B. \\
&\quad - N'_w (z_1 \sin A \cos B + x_1 \cos A) \sin A - N'_q \sin A \cos B. \\
&\quad + N'_r \sin^2 A \sin B. \\
I_{vr} &= + mX'_u (y_1 \sin A - z_1 \cos A \sin B) (x_1 \sin B - y_1 \cos B) \cos A. \\
&\quad + mX'_p (y_1 \sin A - z_1 \cos A \sin B) \sin A. \\
&\quad + mY'_v z_1 \cos B (x_1 \cos B + y_1 \sin B). \\
&\quad - mY'_w z_1 \cos B (x_1 \sin B - y_1 \cos B) \sin A. \\
&\quad + mY'_r z_1 \cos B \cos A + mZ'_v y_1 \sin A (x_1 \cos B + y_1 \sin B). \\
&\quad - mZ'_w y_1 \sin^2 A (x_1 \sin B - y_1 \cos B) + mZ'_r y_1 \sin A \cos A. \\
&\quad + L'_u (x_1 \sin B - y_1 \cos B) \cos^2 A \cos B + L'_p \sin A \cos A \cos B. \\
&\quad - M'_v (x_1 \cos B + y_1 \sin B) \sin B + M'_w (x_1 \sin B - y_1 \cos B) \sin A \sin B. \\
&\quad - M'_r \cos A \sin B - N'_v (x_1 \cos B + y_1 \sin B) \sin A. \\
&\quad + N'_w (x_1 \sin B - y_1 \cos B) \sin^2 A - N'_r \sin A \cos A. \\
M_u &= - mX'_u \cos A \cos B (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad + mY'_v z_1 \sin^2 B + mY'_w z_1 \sin A \sin B \cos B. \\
&\quad + mZ'_v \sin B (x_1 \cos A - z_1 \sin A \cos B) + L'_u \cos^2 A \sin B \cos B. \\
&\quad - mZ'_w (z_1 \sin A + x_1 \cos A) \sin A \cos B. \\
&\quad - M'_v \sin B \cos B - M'_w \sin A \cos^2 B. \\
M_v &= - mX'_u \cos A \sin B (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad - mY'_v z_1 \sin B \cos B + mY'_w z_1 \sin A \sin^2 B. \\
&\quad - mZ'_v \cos B (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad - mZ'_w \sin A \sin B (x_1 \cos A - z_1 \sin A \cos B) + M'_v \cos^2 B. \\
&\quad + L'_u \cos^2 A \sin^2 B. \\
&\quad - M'_w \sin A \sin B \cos B.
\end{aligned}$$

$$\begin{aligned}
M_w &= -mX'_u \sin A (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad -mY'_w \cos A (x_1 \sin A - z_1 \sin B). \\
&\quad -mZ'_w \cos A (x_1 \cos A - z_1 \sin A \cos B) + L'_u \sin A \cos A \sin B. \\
&\quad + M'_w \cos A \cos B. \\
M_p &= -mX'_u (y_1 \sin A - z_1 \cos A \sin B) (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad -mX'_p (x_1 \sin A - z_1 \cos A \cos B) \cos A \cos B. \\
&\quad +mY'_v z_1^2 \sin B \cos B +mY'_w z_1 (y_1 \cos A + z_1 \sin A \sin B) \sin B. \\
&\quad -mY'_q z_1 \sin^2 B -mY'_r z_1 \sin A \sin B \cos B. \\
&\quad +mZ'_v z_1 \cos B (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad -mZ'_w (y_1 \cos A + z_1 \sin A \sin B) (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad +mZ'_q \sin B (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad +mZ'_r \sin A \cos B (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad +L'_u \cos A \sin B (y_1 \sin A - z_1 \cos A \sin B) + L'_p \cos^2 A \sin B \cos B. \\
&\quad -M'_v z_1 \cos^2 B + M'_w \cos B (y_1 \cos A + z_1 \sin A \sin B). \\
&\quad -M'_q \sin B \cos B - M'_r \sin A \cos^2 B. \\
M_q &= mX'_u (x_1 \sin A - z_1 \cos A \cos B)^2. \\
&\quad -mX'_p \cos A \sin B (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad +mY'_v z_1^2 \sin^2 B -mY'_w z_1 \sin B (x_1 \cos A + z_1 \sin A \cos B). \\
&\quad +mY'_q z_1 \sin B \cos B -mY'_r z_1 \sin A \sin^2 B. \\
&\quad +mZ'_v z_1 \sin B (x_1 \cos A + z_1 \sin A \cos B). \\
&\quad +mZ'_w (x_1 \cos A - z_1 \sin A \cos B)^2. \\
&\quad -mZ'_q \cos B (x_1 \cos A - z_1 \sin A \cos B) +mZ'_r \sin A \sin B (x_1 \cos A \\
&\quad \quad - z_1 \sin A \cos B). \\
&\quad -L'_u \cos A \sin B (x_1 \sin A - z_1 \cos A \cos B) + L'_p \cos^2 A \sin^2 B. \\
&\quad +M'_v z_1 \sin B \cos B - M'_w \cos B (x_1 \cos A + z_1 \sin A \cos B). \\
&\quad +M'_q \cos^2 B - M'_r \sin A \sin B \cos B. \\
M_r &= -mX'_u \cos A (x_1 \sin B - y_1 \cos B) (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad -mX'_p \sin A (x_1 \sin A - z_1 \cos A \cos B). \\
&\quad -mY'_v (x_1 \cos B + y_1 \sin B) z_1 \sin B -mY'_w z_1 \sin A \sin B (x_1 \sin B \\
&\quad \quad - y_1 \cos B). \\
&\quad +mY'_r z_1 \cos A \sin B -mZ'_v (x_1 \cos B + y_1 \sin B) (x_1 \cos A - z_1 \sin A \cos B). \\
&\quad +mZ'_w (x_1 \sin B - y_1 \cos B) (x_1 \cos A - z_1 \sin A \cos B) \sin A. \\
&\quad -mZ'_r \cos A (x_1 \cos A - z_1 \sin A \cos B) + L'_u (x_1 \sin B - y_1 \cos B) \\
&\quad \quad \cos^2 A \sin B. \\
&\quad +L'_p \sin A \cos A \sin B + M'_v (x_1 \cos B + y_1 \sin B) \cos B. \\
&\quad -M'_w (x_1 \sin B - y_1 \cos B) \sin A \cos B + M'_r \cos A \cos B. \\
N_u &= mX'_u (x_1 \sin B - y_1 \cos B) \cos^2 A \cos B -mY'_v (x_1 \cos B + y_1 \sin B) \sin B. \\
&\quad -mY'_w (x_1 \cos B + y_1 \sin B) \sin A \cos B -mZ'_v y_1 \sin A \sin B \cos B. \\
&\quad -mZ'_w y_1 \sin^2 A \cos^2 B + L'_u \sin A \cos A \cos B. \\
&\quad -N'_v \cos A \sin B - N'_w \sin A \cos A \cos B. \\
N_v &= mX'_u (x_1 \sin B - y_1 \cos B) \cos^2 A \sin B +mY'_v (x_1 \cos B + y_1 \sin B) \cos B. \\
&\quad -mY'_w (x_1 \cos B + y_1 \sin B) \sin A \sin B +mZ'_v y_1 \sin A \cos^2 B. \\
&\quad -mZ'_w y_1 \sin^2 A \sin B \cos B + L'_u \sin A \cos A \sin B. \\
&\quad +N'_v \cos A \cos B - N'_w \sin A \cos A \sin B. \\
N_w &= +mX'_u (x_1 \sin B - y_1 \cos B) \sin A \cos A +mY'_w (x_1 \cos B + y_1 \sin B) \cos A. \\
&\quad +mZ'_w y_1 \sin A \cos A \cos B + L'_u \sin^2 A + N'_w \cos^2 A. \\
N_p &= mX'_u \cos A (x_1 \sin B - y_1 \cos B) (y_1 \sin A - z_1 \cos A \sin B). \\
&\quad +mX'_p \cos^2 A \cos B (x_1 \sin B - y_1 \cos B). \\
&\quad -mY'_v z_1 \cos B (x_1 \cos B + y_1 \sin B). \\
&\quad +mY'_w (y_1 \cos A + z_1 \sin A \sin B) (x_1 \cos B + y_1 \sin B). \\
&\quad -mY'_q \sin B (x_1 \cos B + y_1 \sin B) -mY'_r \sin A \cos B (x_1 \cos B + y_1 \sin B). \\
&\quad -mZ'_v y_1 z_1 \sin A \cos^2 B +mZ'_w y_1 \sin A \cos B (y_1 \cos A + z_1 \sin A \sin B). \\
&\quad -mZ'_q y_1 \sin A \sin B \cos B -mZ'_r y_1 \sin^2 A \cos B. \\
&\quad +L'_u \sin A (y_1 \sin A - z_1 \cos A \sin B) + L'_p \sin A \cos A \cos B. \\
&\quad -N'_v z_1 \cos A \cos B + N'_w \cos A (y_1 \cos A + z_1 \sin A \sin B). \\
&\quad -N'_q \cos A \sin B - N'_r \sin A \cos A \cos B.
\end{aligned}$$

$$\begin{aligned}
N_q = & -mX'_u \cos A (x_1 \sin B - y_1 \cos B) (x_1 \sin A - z_1 \cos A \cos B) \\
& + mX'_p \cos^2 A \sin B (x_1 \sin B - y_1 \cos B) \\
& - mY'_v z_1 \sin B (x_1 \cos B + y_1 \sin B) \\
& - mY'_w (x_1 \cos B + y_1 \sin B) (x_1 \cos A + z_1 \sin A \cos B) \\
& + mY'_q \cos B (x_1 \cos B + y_1 \sin B) - mY'_r \sin A \sin B (x_1 \cos B + y_1 \sin B) \\
& - mZ'_v y_1 z_1 \sin A \sin B \cos B + mZ'_w y_1 \sin A \cos B (x_1 \cos A + z_1 \sin A \cos B) \\
& + mZ'_q y_1 \sin A \cos^2 B - mZ'_r y_1 \sin^2 A \sin B \\
& - L'_u \sin A (x_1 \sin A - z_1 \cos A \cos B) + L'_p \sin A \cos A \sin B \\
& - N'_v z_1 \cos A \sin B - N'_w \cos A (x_1 \cos A + z_1 \sin A \cos B) \\
& + N'_q \cos A \cos B - N'_r \sin A \cos A \sin B \\
N_r = & mX'_u \cos^2 A (x_1 \sin B - y_1 \cos B)^2 \\
& + mX'_p \sin A \cos A (x_1 \sin B - y_1 \cos B) \\
& + mY'_v (x_1 \cos B + y_1 \sin B)^2 \\
& - mY'_w (x_1 \cos B + y_1 \sin B) (x_1 \sin B - y_1 \cos B) \sin A \\
& + mY'_r \cos A (x_1 \cos B + y_1 \sin B) + mZ'_v y_1 \sin A \cos B (x_1 \cos B + y_1 \sin B) \\
& - mZ'_w \sin A \cos B (x_1 \sin B - y_1 \cos B) + mZ'_r y_1 \sin A \cos A \cos B \\
& + L'_u \sin A \cos A (x_1 \sin B - y_1 \cos B) + L'_p \sin^2 A \\
& + N'_v \cos A (x_1 \cos B + y_1 \sin B) - N'_w \sin A \cos A (x_1 \sin B - y_1 \cos B) \\
& + N'_r \cos^2 A.
\end{aligned}$$

This completes the tabulation of the derivatives of the screw referred to the helicopter axes; the accented letters are the derivatives of the screw referred to its own axes and given above.

The expressions given are perfectly general and will apply to a helicopter having any number of screws disposed on any suitable axes, provided the sideslip velocity is small compared with the axial velocity.

27. Simplification when there are more than two blades.

The following derivatives disappear:—

$$Y'_w \quad Y'_r \quad Z'_v \quad Z'_q \quad M'_w \quad M'_r \quad N'_v \quad N'_q.$$

In view of the periodic nature of the forces when the helicopter has general motion, as shown above, we shall suppose the screws have always at least four blades.

28. The Torque Derivatives.

In steady motion we have

$$Q'_a = -L'$$

Then

$$\begin{aligned}
Q'_{au} &= -L'_u \\
Q'_{ap} &= -L'_p
\end{aligned}$$

and in the case we are considering, *i.e.*, when the sideslip velocity is small, all the other Q'_a derivatives are zero.

Then equation (18) gives

$$2\pi In = L'_u \cdot u' + L'_p \cdot p' + (Q_{en} - Q_{an}) n.$$

To put this in the form (18a) we substitute for u' and p' from (20) and (21) and then Q_{au} is the coefficient of u in the resulting expression, and so on. We find:—

$$\begin{aligned}
Q_{au} &= L'_u \cos A \cos B. \\
Q_{av} &= L'_u \cos A \sin B. \\
Q_{aw} &= L'_u \sin A. \\
Q_{ap} &= L'_u (y_1 \sin A - z_1 \cos A \sin B) + L'_p \cos A \cos B. \\
Q_{aq} &= L'_u (z_1 \cos A \cos B - x_1 \sin A) + L'_p \cos A \sin B. \\
Q_{ar} &= L'_u (x_1 \sin B - y_1 \cos B) \cos A + L'_p \sin A.
\end{aligned}$$

The n Derivatives.

The quantities X_n, Y_n, \dots are expressed in terms of the quantities X'_n, Y'_n, \dots by means of equations (22).

29. We shall now examine some particular cases.

I. Two Contrary-Turning Screws on a Single Axis.

We shall have $y_1 = 0$ and $B = 0$. The derivatives reduce to:—

$$\begin{aligned}
 X_u &= X'_u \cos^2 A + Z'_w \sin^2 A. & X_v &= 0. \\
 X_w &= (X'_u - Z'_w) \sin A \cos A. & X_p &= 0. \\
 X_q &= X'_u (z_1 \cos A - x_1 \sin A) \cos A + Z'_w (z_1 \sin A + x_1 \cos A) \sin A. \\
 X_r &= 0. \\
 Y_u &= 0. & Y_v &= Y'_v. & Y_w &= 0. \\
 Y_p &= -z_1 Y'_v. & Y_q &= 0. & Y_r &= x_1 Y'_v. \\
 Z_u &= (X'_u - Z'_w) \sin A \cos A. & Z_v &= 0. \\
 Z_w &= X'_u \sin^2 A + Z'_w \cos^2 A. \\
 Z_p &= 0. & Z_r &= 0. \\
 Z_q &= X'_u (z_1 \cos A - x_1 \sin A) \sin A - Z'_w (z_1 \sin A + x_1 \cos A) \cos A. \\
 L_u &= 0. & L_w &= 0. \\
 L_v &= mY'_v z_1. \\
 L_p &= -mY'_v z_1^2 + L'_p \cos^2 A + N'_r \sin^2 A - mZ'_r \sin^2 A. \\
 L_q &= -mY'_q z_1 - L'_u x_1 \sin A \cos A - N'_w (z_1 \sin A + x_1 \cos A) \sin A. \\
 L_r &= mY'_v x_1 z_1 - (N'_r - L'_p) \sin A \cos A. \\
 M_u &= mX'_u (z_1 \cos A - x_1 \sin A) \cos A - mZ'_w (z_1 \sin A + x_1 \cos A) \sin A. \\
 M_v &= 0. \\
 M_w &= mX'_u (z_1 \cos A - x_1 \sin A) \sin A - mZ'_w (z_1 \sin A + x_1 \cos A) \cos A. \\
 M_p &= mX'_p (z_1 \cos A - x_1 \sin A) \cos A + mZ'_r (z_1 \sin A + x_1 \cos A) \sin A - z_1 M'_v. \\
 M_q &= mX'_u (x_1 \sin A - z_1 \cos A)^2 + mZ'_w (x_1 \cos A + z_1 \sin A)^2 + M'_q. \\
 M_r &= mX'_p (z_1 \cos A - x_1 \sin A) \sin A - mZ'_r (x_1 \cos A + z_1 \sin A) \cos A + x_1 M'_v. \\
 N_u &= 0. & N_v &= x_1 \cdot mY'_v. & N_w &= 0. \\
 N_p &= -mY'_v z_1 x_1 - (N'_r - L'_p) \sin A \cos A. \\
 N_q &= mY'_q x_1 + L'_u (z_1 \cos A - x_1 \sin A) \sin A - N'_w (x_1 \cos A + z_1 \sin A) \cos A. \\
 N_r &= N'_r \cos^2 A + L'_p \sin^2 A + mY'_v \cdot x_1^2.
 \end{aligned}$$

We also have in this case:—

$$\begin{aligned}
 Q_{au} &= L'_u \cos A. & Q_{av} &= 0. \\
 Q_{aw} &= L'_u \sin A. \\
 Q_{ap} &= L'_p \cos A. \\
 Q_{aq} &= L'_u (z_1 \cos A - x_1 \sin A). \\
 Q_{ar} &= L'_p \sin A. \\
 X_n &= X'_n \cos A - Z'_n \sin A. & Y'_n &= 0. \\
 Z_n &= X'_n \sin A + Z'_n \cos A. \\
 L_n &= L'_n \cos A - N'_n \sin A. \\
 M_n &= -m (X'_n z_1 - Z'_n x_1). \\
 N_n &= L'_n \sin A + N'_n \cos A.
 \end{aligned}$$

The stability equation is now:—

$X_u - \lambda$	0	X_w	0	$\lambda X_q - g \cos \theta_0$	0	X_n	= 0
0	$Y_v - \lambda$	0	$\lambda Y_p + g \cos \theta_0$	0	$\lambda (Y_r - V) + g \sin \theta_0$	0	
Z_u	0	$Z_w - \lambda$	0	$\lambda (V + Z_q) - g \sin \theta_0$	0	Z_n	
0	L_v	0	$\lambda L_p - A\lambda^2$	L_q	$\lambda L_r + E\lambda^2$	L_n	
M_u	0	M_w	M_p	$\lambda M_q - B\lambda^2$	M_r	M_n	
0	N_v	0	$\lambda N_p + E\lambda^2$	N_q	$\lambda N_r - C\lambda^2$	N_n	
Q_{au}	0	Q_{aw}	Q_{ap}	Q_{aq}	Q_{ar}	$2\pi I\lambda + Q_{an} - Q_{en}$	

In forming the derivatives it must be remembered that x_1 and z_1 will be different for the two screws, and that the following must have their signs changed for the left-handed screw:—

$$X'_p, Y'_q, Z'_r, L'_u, M'_v, N'_w.$$

This determinant is capable of some reduction, but it does not seem profitable to attempt the reduction until we know whether any of the terms are negligible.

If the angle A is zero X_w, Z_u, Q_{aw} and Q_{ar} vanish.

If, in addition, the c.g. of the whole machine lies on the axis of the screws the following derivatives disappear as well:—

$$X_q, Y_p, L_v, L_q, L_r, M_u, M_p, N_p, Q_{aq}.$$

When descending vertically with the screws free the torque is zero and $Z'_w = 0$, so that when A and z_1 are zero, we also have $Z_w = 0, Z_q = 0, M_w = 0, M_q = M'_q, Q_{an} = 0, \theta = 90^\circ$.

The equation has now reduced to:—

$$\begin{vmatrix} X_u - \lambda & 0 & 0 & 0 & 0 & X_n \\ 0 & Y_v - \lambda & 0 & 0 & \lambda(Y_r - V) + g & 0 \\ 0 & 0 & \lambda L_p - A\lambda^2 & 0 & E\lambda^2 & L_n \\ 0 & 0 & 0 & \lambda M_q - B\lambda^2 & M_r & M_n \\ 0 & N_v & E\lambda^2 & N_q & \lambda N_r - C\lambda^2 & N_n \\ Q_{au} & 0 & Q_{ap} & 0 & 0 & 2\pi I\lambda \\ & & & & & + Q_{an} \end{vmatrix} = 0$$

II. Two Contrary-Turning Screws on Separate Shafts.

If we suppose the two shafts to be symmetrically placed with respect to the xz plane, y_1 and B will be equal and of opposite signs for the two screws. The derivatives can be written down from the general expressions given above, and we find that the extra axes which are introduced are L_u, M_v, N_w .

This completes for the moment the presentation of the stability equations. In a later paper I shall hope to give the results of some numerical investigations carried out with a view to throwing some light on the design of a practical helicopter.

Errata in October issue:

- p. 392, equation (5) for $\sin^2 \phi$ read $\cos^2 \phi$.
 „ „ (9) delete 2.
 „ „ (10) for π^3 read $\pi^3/2$.
 p. 401, line 10, for Z read $-Z$.
 p. 402, for a read β .
 „ „ Z „ $-Z$.



ASSOCIATE FELLOWSHIP EXAMINATION, September 25th-26th, 1922.

EXAMINATION PAPER ON STRENGTH AND ELASTICITY OF MATERIALS AND THEORY OF STRUCTURES.

Ten questions only to be attempted.

1. Define stress, strain, elastic limit, yield point, permanent set, Poisson's ratio, and ultimate stress.

2. State Hooke's Law. Is this applicable to all materials? A duralumin tube 2 in. external diameter and $\frac{1}{8}$ in. in wall thickness encloses a steel tube 1 $\frac{3}{4}$ in. external diameter and $\frac{1}{8}$ in. wall thickness. The tubes are of the same length, and are rigidly attached to each other at the ends. If this composite tube is used as a tie rod what proportion of the tension is taken by each tube?

Young's modulus for steel = 30×10^6 lbs. per sq. in.

Young's modulus for duralumin = 10.5×10^6 lbs. per sq. in.

3. A steel bar 1 sq. in. in cross sectional area and 20 in. long carries a load of one ton suspended from it. What is the maximum stress in the bar—

(a) When the load is applied gradually.

(b) When the load is applied suddenly.

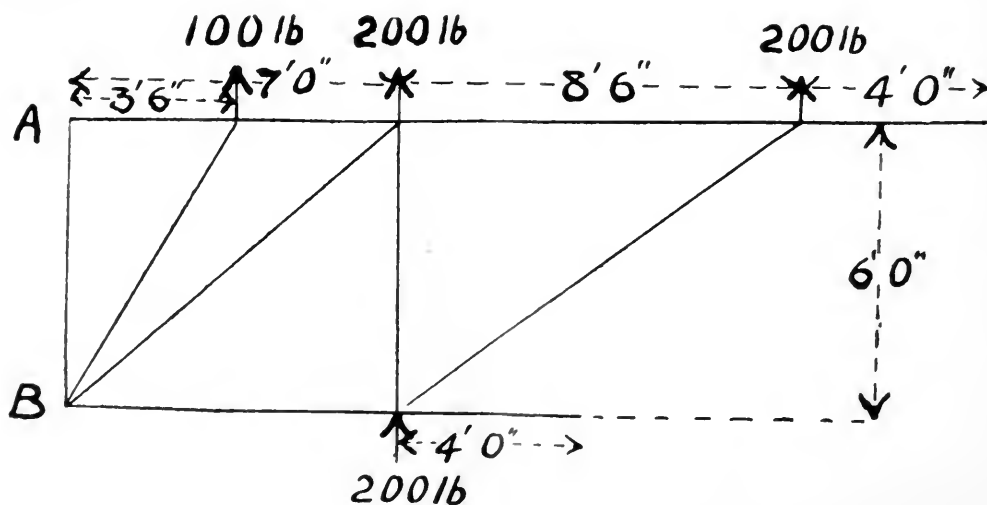
(c) When the load is allowed to drop through $\frac{1}{8}$ in. before it is taken on the bar.

4. Describe the tests you would apply to samples of silver spruce intended for aeroplane construction. Give the object of each test and the nature of the result you would hope to obtain.

5. What tests would you apply to a consignment of three-ply to ensure that it was suitable for aeroplane structural work?

6. A beam is pin-jointed at the ends and carries a uniformly distributed load of 20 lbs. per inch run. How would you determine the deflection at any point in the beam?

7. A pin-jointed beam is subjected to an irregularly distributed load. Given the loading diagram, show how the shear force and bending moment curves can be found.



8. The truss shown in the figure is supported at *A* and *B*, and subjected to the loads indicated. Assuming the truss to be everywhere pin-jointed, find the loads in all members.

9. Discuss the method of failure of a long, thin strut. A streamline strut of silver spruce is 72 in. long between pin joints. Its maximum axis is $4\frac{1}{2}$ in., minimum $1\frac{1}{2}$ in. in length, and it is parallel throughout its length. Calculate the axial load under which it will fail given that the moment of inertia of a streamline section is $BD^3/24$, where *B* and *D* are lengths of the maximum and minimum axes respectively, and that *E* for spruce is 1.6×10^6 lbs. per sq. in.

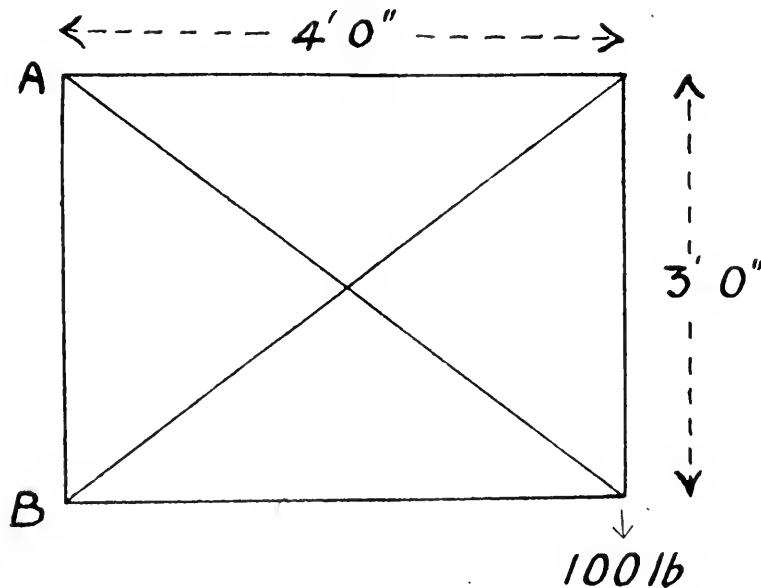
10. Show how you would calculate the maximum stress in a pin-jointed strut which carries an evenly distributed lateral load in addition to its axial thrust.

11. State the theorem of three moments in its usual form. Show how it may be used to calculate the reactions at the interplane struts in an aeroplane spar.

12. What modifications are required to the theorem of three moments to render it accurate for the calculation of spar stresses in an aeroplane? What approximate corrections are sometimes applied in practice in place of using the generalised equation?

13. Deduce an expression for the strain energy stored in a bar subjected to an axially applied tension or compression.

14. What do you understand by a redundant structure? Describe a method by which the stresses in such a structure can be calculated.



15. The pin-jointed structure shown is composed of steel members each $\frac{1}{4}$ of a sq. in. in cross sectional area. The frame is supported at *A* and *B*, and a load of 100 lbs. is hung on as shown. Neglecting any buckling of the strut members, determine the loads carried by each member of the frame.

EXAMINATION PAPER ON AERODYNAMICS.

(Time, 3 hours.)

Six questions only to be answered.

1. Estimate the drag at an airspeed of 110 m.p.h. of 55 ft. of streamline, interplane struts, 1.25 in. thick, and 160 ft. of streamline wires, 0.10 in. thick, ignoring mutual effects. Make careful sketches (a) of a suitable section for the struts, to an enlarged scale; (b) of the attachment of strut and wires to a spar.

2. A disc, 10 in. dia., held normal to the wind, gives a pressure distribution over its front and back face in accordance with the following table:—

Radius (in.)	...	0	1.0	2.0	3.0	4.0	4.5	5.0
Front (in. of water)	0.40	0.39	0.37	0.34	0.28	0.18	0.00	
Back (in. of water)	0.20	0.22	0.24	0.26	0.28	0.14	0.00	

Estimate the drag coefficient of the disc.

3. A seaplane of the parasol-monoplane type is 30 ft. in span. Midway between the floats is a water vane, to assist getting off, geometrically similar to the wing. The leading edge and chord of the vane are parallel to those of the wing, and it is 2 ft. 6 in. in span. Neglecting any mutual effects, explain why the lift of the vane does not remain a constant fraction of the lift of the wing during flight. Also show that while the machine taxis with the vane sufficiently deeply immersed in water having $1/12$ th the kinematic viscosity of air, the reverse is true, whatever the speed. In the latter case, calculate the constant relation between the lifts, taking water as weighing 64 lbs. per cu. ft. Establish any formula to which you may refer.

4. (a) A model to twice full scale of a wing tip float, tested in a wind channel, gave the following results:—

Speed (ft. per sec.)	...	60	70	80	90
Drag (lbs.)	...	2.07	2.65	3.30	4.05

Find the air-drag of the float at 150 ft. per sec.

(b) A flying boat hull is thought to have a water-drag of 4,000 lbs. at 20 m.p.h. At what speed should a $1/20$ th scale model be towed in a tank to check this? What drag would the model then have if the estimate for full size were correct?

5. Carefully sketch the sections of two wings; one suitable for high speed, the other giving a high maximum lift. Show in a single diagram marked with proper scales, the curves of $k_T - \alpha$ and $L/D - \alpha$ you would expect from a model test in each case. Making use of your diagram, explain any case of a prospective machine in which the high lift wing might be preferred to the other.

6. An aeroplane, weighing 2,600 lbs., has a speed range of 51 to 120 m.p.h. at low altitude. The thrust horse-power available falls from 180 at ground to 85 at 20,000 ft. The wings have the following characteristics:—

Lift coef.	.090	.165	.252	.310	.422	.480	.500 (max.)
Lift/drag	9.3	13.0	13.0	12.3	9.8	9.0	6.0

Estimate the maximum rate of climb at ground level and at 20,000 ft. (Relative density = 0.53.) Ignore airscrew effects.

7. Discuss the economic advantage of flying at considerable altitude. An aeroplane is flown due north at an altitude of 10,000 ft. ($\rho = .00175$), at an indicated airspeed of 90 m.p.h. There is a steady north-westerly wind of 30 m.p.h. Find the distance covered in one hour.

8. Briefly discuss the question as to whether an aeroplane, initially flying in a straight horizontal path, gains or loses speed on a properly banked turn. An aeroplane is put into a horizontal circular path of 200 ft. radius. There is no side-slipping and the steady speed becomes 80 m.p.h. What record would the accelerometer make of the manœuvre?

9. A two-bladed airscrew turning at 1,260 r.p.m. is required to drive an aeroplane at 130 ft. per sec. At 3 ft. 9 in. radius the angle of incidence of the section of the blade is to be four degrees, and the local thrust 110 lbs. per ft. run. At what angle must the section be inclined to the plane of rotation? (Assume

that the ratio of the inflow factor to the outflow factor is 0.35, and neglect rotation of the airstream.)

10. A glider is found to have a tendency to get into a spin. An attempt to correct this produces spiral instability. Describe each form of instability, suggesting what alteration was probably made. State what further steps you would take to ensure satisfactory flight.

EXAMINATION PAPER ON HEAT ENGINES.

Answers are not expected to all the questions, but full answers to six should be attempted, and should include the first three questions on the paper.

1. Why does the power of an internal combustion engine fall off with increase in altitude? What methods have been proposed to counteract this decrease? Discuss briefly the respective merits of the various proposals.

2. Describe briefly one form of device fitted to aero engine carburettors to enable the pilot to control the mixture strength at different altitudes. Why is such a device fitted?

3. Why is a high mechanical efficiency very desirable in any engine and particularly in an aero engine? An internal combustion engine, when developing 400 brake horse-power, was found to have a mechanical efficiency of 88 per cent. It was also found that the piston friction alone amounted to 50 per cent. of the total losses. Estimate the h.p. wasted in piston friction, and express the result in B.T.U.'s. What becomes of this heat?

4. Give the equation correcting pressures and volumes for adiabatic compression and expansion of a gas. The following data relates to the compression of 100 volumes of a gas:—

Volumes.	Pressures lbs. sq. in. (gauge).
100	0
50	25.3
30	65.3

Show how to determine the value of the index " n " from the above data.

5. It is found that the pressures obtained by ignition of a petrol-air mixture are considerably lower than those calculated from the simple gas laws. How do you account for this?

6. Define indicated thermal efficiency, brake thermal efficiency and relative indicated thermal efficiency. An engine running on a brake test at 1,500 r.p.m. lifts a net weight of 117 lbs. at a brake arm radius of 3 ft., and consumes one pint of fuel in 70 seconds. The lower heat value of the fuel is 18,900 B.T.U. per pint, the compression ratio 5 : 1 and the mechanical efficiency 87 per cent. Find the indicated thermal efficiency, brake thermal efficiency and the relative indicated thermal efficiency.

7. Discuss the balance of an eight-cylinder 90 deg. Vee type engine with all the cranks in one plane. In such an engine the reciprocating weight for each cylinder is 10 lbs., the stroke being 6 in. and the connecting rod length 12 in. What is the magnitude direction and frequency of the secondary out of balance force at a speed of 1,800 r.p.m.? Assume that the connecting rods are all attached directly to the crank pins.

8. Show by means of a clock-face diagram the usual disposition of the cranks of a six-cylinder four-stroke cycle petrol engine, and give a suitable firing order for the six cylinders.

9. Why is it particularly desirable that, in six-cylinder line and twelve-cylinder Vee type engines, the engine structure shall have considerable longitudinal stiffness considered as a beam? Compare various types of engine structures from this point of view, including British and German practice.

10. What are the sources of loading on the big end bearing of a single acting four-stroke cycle stationary engine? How is the loading affected by variations in speed and load? Assuming constant engine speed and considering the conditions which exist when the engine is running on full throttle at ground level and at a considerable altitude, do any of the sources of loading vary in amount, and if so, which and in what sense?

11. What are the considerations which lead one to use (a) multiple inlet valves and (b) multiple exhaust valves?

12. In high duty engines such as aero engines having plain bearings, it is common practice to circulate considerable quantities of lubricant through the bearings. What are the reasons for this procedure? What is meant by a "dry sump" lubrication system, and what are the reasons underlying its adoption on aero engines?

13. What is understood by the expression "bad distribution" in connection with the running of a multi-cylinder petrol engine? What influence has bad distribution on the performance of an engine?

14. Discuss the relative advantages and disadvantages in the use of aluminium alloys, cast-iron, and steel for (a) the pistons, and (b) the cylinders of water and air-cooled aero engines.

15. Discuss, from the aircraft designer's point of view, the various types of engines (straight line, Vee, radial and rotary) as applied to (a) commercial and (b) military service, indicating the types of machines for which each type of engine is more particularly suited.

ASSOCIATE FELLOWSHIP EXAMINATION, PART II.

MATHEMATICS.

1. A cone of height h and circular base of radius a is composed of material of density ρ . Find the depth to which it will float vertex downwards in a fluid of density σ . Hence show that if it be depressed vertically by a small amount beyond this depth it will oscillate when released, and find the period of a small oscillation.

2. State Newton's Second Law of Motion. A body is projected with an initial velocity V in a medium in which the only force that operates is a resistance of magnitude kv^n along the line of motion, k and n being constants and v the velocity of the body. Show that the body will not come to rest in a finite distance unless n is less than 2.

3. Show that in the motion of a particle of mass m in a plane, under given forces, the latter must be equivalent to mdv/dt along, and mv^2/ρ at right-angles to the path, ρ being the radius of curvature and v the velocity at the point. A closed elastic band fits tightly round the circumference of a wheel of radius a , the tension being T_0 . Find the angular speed of the wheel in order that the band may just leave it.

4. Explain the terms *dimensions* and *homogeneity of dimensions* with reference to the terms of a physical equation. A body is projected with velocity V under an acceleration A whose magnitude and direction are variable and

unknown. Show that if the speed of the body is v at any instant when a distance s has been traversed then the acceleration A must be expressible in the form—

$$A = V^2/s \int (v/V),$$

where \int is some unknown function. Verify this formula for the case of a body projected vertically under gravity.

5. Sketch roughly the graph of the expression—

$$y = x(x^2 - 1)/(x^2 - 4);$$

hence determine the number and signs of the real roots of the equation—

$$x(x^2 - 4) - (x^2 - 1) = 0.$$

6. Define *direction cosines*. Prove that if two lines have direction cosines (l_1, m_1, n_1) and (l_2, m_2, n_2) the angle θ between them is given by—

$$\cos \theta = l_1 l_2 + m_1 m_2 + n_1 n_2.$$

If possible without using tables, find in degrees the angle between the two lines having direction cosines proportional to $(1, 2, 2)$ and $(2, 4, 3)$.

7. State and prove the formula for integration by parts. Evaluate—

$$(1) \quad \int_0^{\pi/2} x \sin x \, dx.$$

$$(2) \quad \int_0^{\infty} \frac{dx (x^2 + a^2)}{(x^2 + b^2)(x^2 + c^2)}.$$

8. State and prove the conditions that must be satisfied by the maximum and by the minimum values of the function $y = f(x)$. Investigate the turning points of the functions—

$$(i) \quad (x^2 + ax + b)/(x^2 + 1), \quad (ii) \quad (\sin x)/x.$$

9. Write down Maclaurin's Theorem. Expand $\cosh x$ in ascending powers of x and hence show that—

$$\cos ix = \cosh x \quad \text{where } i^2 = -1.$$

10. The curve $y = f(x)$ is rotated round the axis of x . Find an expression for the volume enclosed between the resulting surface and the planes $x = x_1$ and $x = x_2$. Deduce the volume of a right circular cone of height h and radius of base r .

11. Explain precisely what is implied by the phrase “neglecting terms of higher order than the first.” If a differential equation is so simplified by applying this process that it becomes capable of simple solution, how far would you be justified in relying on the results obtained by such a solution?

12. State carefully any problem represented by a differential equation of the type—

$$d^2y/dt^2 + 2k \, dy/dt + n^2y = 0$$

where k and n are constants. Solve the equation completely in the case cited and interpret the results.

NAVIGATION AND METEOROLOGY.

Not more than seven questions to be answered.

1. Describe meteorological conditions in which fog might be expected at aerodromes situated (a) on a high level plateau, (b) on flat, low-lying ground.
2. The centre of a rather deep cyclone is situated over the North of Scotland, and is moving eastwards. Describe weather conditions over Western Europe during the following 24 hours.
3. Write a short essay upon *either* (a) variation of wind with height, *or* (b) variation of temperature with height.
4. Write short notes on the following :—
 - (a) "Gradient" or "geostrophic" wind.
 - (b) Line squalls.
 - (c) The stratosphere.
 - (d) Haze and visibility.
 - (e) Meteorological anemometers.
 - (f) The errors of airspeed indicators, when used at heights.
5. Meteorological information gives the wind at 5,000ft. at 20 m.p.h., from the south-west. An aeroplane has to fly to an aerodrome 100 miles due east from the starting point. Show how the time occupied by the flight and the required compass bearing could be calculated.
6. Describe any type of turn indicator, and discuss the advantages of these instruments for use in flying through cloud.
7. Describe briefly the working of any type of sextant for use on aeroplanes, and show, in detail, how to calculate your position from sextant observations of the sun or stars.
8. Write short notes on the following :—
 - (a) Great circle route.
 - (b) Somner lines.
 - (c) Magnetic variation.
 - (d) Magnetic deviation.
 - (e) Errors of altimeters.
 - (f) Course setting instruments.
9. Describe fully any method of determining your position when flying in an aeroplane by means of direction-finding wireless.
- *10. Discuss the causes which give rise to the unsatisfactory working of compasses when used in an aeroplane, and why are similar troubles not noticed on ships?

METALLURGY.

Questions one and two, and four of the remainder are to be answered.

1. Explain the meaning of the terms normalising, hardening, tempering, bluing, as applied to steel. Give the normalising and hardening temperatures of steels of the following compositions :—

	A	B	C	D	E	F
Carbon, per cent ...	0.10	0.40	0.30	0.30	0.35	0.25
Manganese, per cent....	0.50	0.60	0.35	0.65	0.45	0.50
Nickel, per cent. ...	nil	nil	3.75	3.25	0.50	4.30
Chromium, per cent. ...	nil	nil	0.85	0.10	12.5	1.20

State the quenching medium you would employ in treating (a) a 3in. round bar, (b) a $\frac{1}{2}$ in. round bar of each of the above steels.

2. Give the approximate tensile and impact properties of 1in. round bars of the six steels given in Question 1 after cooling in (a) air, (b) water, (c) oil. Give the approximate maximum stress, elongation per cent. and impact value of steels B, C, and D after hardening in oil in 1in. round bars from the temperature you think best, followed by tempering at 200deg. C., 400deg. C., 600deg. C. respectively. Are the impact values of the six steels given in Question 1 affected by the mode of cooling from these tempering temperatures?

3. State the essential features of the operation of case-hardening. Give the approximate chemical composition of three case-hardening steels, and state any variation from the procedure you have described when producing a case-hardened article in the three steels you select.

4. What is duralumin? State its approximate chemical composition, its mechanical properties when properly treated, and the heat treatment that should be given to it in order to produce these properties.

5. What are the principal alloys of aluminium, either wrought or cast, used in aircraft? Give the approximate mechanical properties of each alloy and its specific gravity.

6. What are the predominant features of (a) cast, (b) forged or drop forged, (c) rolled metals? What is the effect of micro-structure upon the mechanical properties of steel?

7. What materials would you employ for five of the following purposes:—

- (a) An exhaust valve in a hot engine.
- (b) Dip-brazing of steel fittings.
- (c) Fork ends.
- (d) Tie rods.
- (e) Gudgeon pins.
- (f) Reduction pinions.
- (g) Radiator tubes.
- (h) Petrol piping.
- (i) Petrol tank.

Give the approximate chemical composition of the material chosen for each part.

8. Give the approximate chemical composition and general mechanical properties of three of the following:—

- (a) Muntz metal.
- (b) Delta metal.
- (c) Naval brass.
- (d) Cast phosphor bronze.
- (e) Gunmetal.



REVIEWS.

Grundlagen der Flugtechnik. Dr. H. G. Bader.

The aim of this book is to give an account of all the aerodynamic calculations required for the design of an aeroplane, other than those dealing with the strength of the structure, and on the whole this object is carried out successfully. The treatment of the problems is almost purely theoretical, and experimental results are introduced only to indicate the accuracy of the theory or to provide numerical values for the constants which occur in the formulæ.

Starting with a rather inadequate account of the theory of the lift and drag of wing structures, the author passes on to a full treatment of the performance of an aeroplane, and of the choice of design to secure high speed, high rate of climb or great endurance. The balance of the aeroplane is next considered in detail, together with the problem of securing weathercock stability. The author advocates that the stability should be positive in this sense, but that the margin of stability should be small. This is followed by a full treatment of the longitudinal and lateral stability of the aeroplane, which, however, contains no new features. Finally there is a most interesting chapter on the problems of getting off and landing.

On the whole the treatment of the various problems is most satisfactory, and although often differing in form from the usual English practice, the work is really identical in all essential points. The only real gap in the book is the failure to give any account of the theory of the airscrew, this work being replaced by a couple of diagrams of airscrew characteristics. This gap is the more noticeable as a very full account is given of the effect of the airscrew slipstream and of its effect on the angle of downwash, but it is the only gap in a very full treatment of the aerodynamic problems of aeroplane design.

Direction and Position Finding by Wireless. R. Keen. Wireless Press.

A book dealing exclusively with directional wireless is welcome, particularly as most of the recent published information on this subject has appeared in the proceedings of scientific societies and is therefore not readily available, nor likely to be fully understood by the general reader. The book is very well illustrated by diagrams and photographs, and the subject is presented in such a manner that it should be quite clear to those whose knowledge of wireless is limited.

The Author has adopted an excellent system for reference in the text to published articles dealing more fully with a particular point. At the end of the book a bibliography is given, arranged in chronological order, and the items are consecutively numbered, these numbers being quoted in the text when reference to the paper would give additional information. This system could be adopted in other technical works with advantage.

The book deals chiefly with the Marconi-Bellini-Tosi system, particularly as applied to shore and ship installations, and though these descriptions are very interesting, the chapter on aircraft installations will be of the greatest value to readers of the AERONAUTICAL JOURNAL. This chapter is unfortunately one of the shortest in the book, and the aircraft sets are therefore not described in great detail. The use of the wing coil system for taking bearings or homing on a sending station is discussed and the effect of drift explained. The Robinson

system, used by the Royal Air Force, is briefly described and illustrated by photographs, and particulars are given of a Marconi-Bellini-Tosi set for aircraft.

Very little space is allotted to the directional transmitter or "Radiophare," and this is to be regretted as this system may well prove to be of the greatest value for aircraft navigation.

The chapters dealing with maps and position finding explain the use of directional wireless for navigation in a simple and interesting manner. The way in which polarisation, reflection and refraction of the electro-magnetic waves give rise to errors, and the methods employed to reduce these errors, are dealt with in a chapter headed "Night Effect," and by the aid of numerous illustrations this rather complicated subject is rendered easy to understand.

The final chapter gives notes on field and nautical astronomy, chiefly for the guidance of those erecting ground stations, and it is in this chapter that the only error noticed in the book occurs. The point X in Fig. 244 should be on the ecliptic as it is the true position of the sun on the celestial concave.

The Author has completed the task he set himself in a very satisfactory manner, and if the criticism is made that too little space has been devoted to aircraft installations, the Author would be perfectly justified in replying that he has allotted space in proportion to the importance of the subject. There is no doubt that directional wireless is not used on aircraft to any great extent at the present time, but it is to be hoped that the promise shown by this adjunct will one day be realised and in some future edition of this book the section dealing with aircraft sets may rival in importance the chapters dealing with the installations in surface craft. Meanwhile, the book can be confidently recommended to those interested in the subject.



CORRESPONDENCE.

Cambridge Road,
South Farnborough.

To the Editor of the AERONAUTICAL JOURNAL.

DEAR SIR,—The article on helicopters by Mr. J. Case, in the October issue, mentions a serious discrepancy in calculating the thrust at zero advance by the multiplane interference theory, according as the corrections are estimated from the experimental data of R. and M. 639, or are calculated by the vortex theory of aerofoils as in R. and M. 752. In the first case a thrust of 2,000lb. per blade was obtained, while in the second case the value was 370lb., and this last figure was in agreement with model tests of the airscrew. The following notes are an attempt to account for this discrepancy.

The experimental data of R. and M. 639 were obtained with aerofoils of aspect ratio 6, while the calculations for the helicopter were based on the actual aspect ratio 3 of the blades. Calculations with aspect ratio 6, however, would give a thrust of 700lb. instead of 370lb. as obtained with aspect ratio 3.

In the second place the calculations made on the vortex theory have shown that, owing to errors of extrapolation, the experimental results of R. and M. 639 may be considerably in error. This error depends on the span-gap ratio of the series of aerofoils, being negligible when this ratio is unity and rising to 5 per cent. when the ratio is 6. In the case of the helicopter under discussion this ratio was as high as 33 and the error of extrapolation can therefore be estimated as of the order of 25 per cent. If this correction is made the thrust per blade is found to be 750lb. instead of 2,000lb. and this figure is in reasonable agreement with the estimate made by use of the vortex theory.

It appears from this discussion that if the multiplane interference theory is to be used with success the correction factors should be calculated by the vortex theory as in R. and M. 752 and that the mean aspect ratio of the blades should be used.

Yours faithfully,
H. GLAUERT.



THE AËRONAUTICAL JOURNAL.

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All communications should be addressed to the Editor.

No. 144.

DECEMBER, 1922.

VOL. XXVI.

Notices of the Royal Aëronautical Society.

Election of Members.

The following Members were elected at a Council Meeting held on November 21st:—

Fellow.—C. R. Fairey.

Associate Fellows.—H. J. Mackintosh and S. E. Taylor.

Member.—Major H. G. Brackley, D.S.O., D.F.C.

Foreign Member.—J. Parker van Zandt.

SCOTTISH BRANCH.—*Associate Member.*—F. O. W. J. Buchanan.

R.38 Memorial Prize.

On the next page will be found the full regulations for the annual award of the R.38 Memorial Prize for papers on airships. It will be noticed that for the coming year's award synopses of papers should reach the Secretary on or before the 31st of the present month and the full paper not later than March 31st, 1923.

The Council have given the commission for the design of the memorial tablet to those who were lost in the airship, to be placed in the Library, to Mr. Paul Cooper, who has already presented preliminary sketches and is now engaged upon the design.

Library.

The Council are glad to announce that through the kind assistance of Lord Weir a successful application has been made to the authorities of the Carnegie United Kingdom Trust for a grant towards the purchase of volumes from a valuable collection of early historical books on aeronautics which would otherwise have been sold to an American collector. Owing to the generosity of the Carnegie Trustees it is possible to fill a large number of the gaps in the Society's collection, as well as to obtain a number of modern textbooks. When the purchase is concluded the Society's Library will be indubitably the most complete and representative collection of books on all aspects of aeronautics in this country.

At the request of the Carnegie Trustees the books in the Library will in future be available to students applying through the Central Library for Students.

Students' Visit.

A visit to the collection of aeronautical exhibits at the Science Museum, Exhibition Road, South Kensington, has been arranged for Saturday afternoon, December 16th, when Mr. Davy, in charge of the aeronautical section of the

Museum, will conduct the party round. Students who wish to take advantage of this opportunity will meet at the entrance to the Southern Galleries of the Science Museum at 3.0 p.m.

Technical Discussion.

The first "Technical Discussion," open to all technical members of the Society, was held in the Library at 3.0 p.m. on November 30th, when Mr. H. Glauert's paper, "Theoretical Relationships for the Lift and Drag of an Aerofoil Structure," was discussed. The discussion was adjourned to 3.0 p.m. on Wednesday, January 10th, 1923.

Additions to the Library.

The following books have been received and placed in the Library:— "Direction and Position Finding by Wireless," by R. Keen; "Index to Periodicals K. Science and Technology," by the Library Association; "Our Future in the Air," by General P. R. C. Groves; "The Aerofoil and the Screw Propeller," by F. W. Lanchester; "L'Aeronautique," by Comte de la Vaulx; "The Internal Combustion Engine" (Vol. I.), by H. R. Ricardo; "Aircraft Steels and Materials," by various authors; "Sir Walter Raleigh and the Air History," by H. A. Jones; "The Internal Combustion Engine," by Major Wimperis; Transactions of the Newcomen Society (Vol. I.).

Forthcoming Arrangements.

Dec. 14, 7.0 p.m.—Society's Library, Students' Section. "Navigation of Aircraft," by Mr. A. P. Rowe. Chairman, Sir A. Whitten Brown.

„ 16, 3.0 p.m.—Visit to Science Museum. Students' Section. Meet at Museum entrance, Exhibition Road, S.W.7.

1923.

Jan. 4, 5.30 p.m.—Royal Society of Arts. Herr Junkers, "Metal Aeroplanes."

„ 10, 3.0 p.m.—Society's Library. Adjourned Technical Discussion.

„ 11, 3.0 p.m.—Royal Society of Arts. *Juvenile Lecture*. Mr. R. A. Frazer, "Model Aircraft."

Students' Smoking Concert.

It has been suggested that a smoking concert should be held by the Students in London early in the new year, and it is proposed to discuss the matter with a view to coming to some decision at the Students' Meeting on the 14th of this month. It is hoped that Students will make a special point of attending this meeting, or if unable to do so will write to the Honorary Secretary saying whether or not they are in favour of the proposal.

W. LOCKWOOD MARSH, *Secretary*.



R38 MEMORIAL PRIZE.

The Council of the Royal Aeronautical Society have decided to institute forthwith from the funds of the R.38 Memorial Research Fund an annual prize for a technical paper on Airships. The regulations covering the award of this prize are given below, from which it will be seen that the date for the receipt of the names of intending competitors for the first award is December 31st, 1922, while the papers themselves must reach the Secretary on or before March 31st, 1923.

REGULATIONS.

From the income of the above fund a sum of twenty-five guineas will be offered annually as a prize for the best paper received by the Royal Aeronautical Society, on some subject of a technical nature in the science of aeronautics. Other things being equal, preference will be given to papers which relate to airships.

The prize is open to international competition. The Royal Aeronautical Society retain the right to withhold the prize in any year, if it is considered that no paper is of sufficient merit to justify an award.

Intending competitors should send their names to the Secretary of the Royal Aeronautical Society, 7, Albemarle Street, London, W.1, on or before December 31st of each year, with such information in regard to the projected scope of their papers as will enable arrangements to be made for their examination. The closing date for the receipt of papers will be March 31st in each year.

Papers should in all cases be typed, and a copy should be retained by the author as the Society can take no responsibility for the loss of copies submitted to it.

Successful papers will become the absolute property of the Society and will in most instances be published in the Society's Journal. In regard to unsuccessful papers, the Society retains the right of publication in its Journal, but in each case will notify the author, shortly after the award, whether it intends to exercise this right; if not, the author will be free to publish elsewhere. A signed undertaking must accompany each paper to the effect that publication has not already taken place and that the author will not communicate it elsewhere until the Society's award is published. Due acknowledgment must be made by the author of the source of any special information.



THE ELASTIC CONSTANTS OF SPRUCE AS INFLUENCED BY MOISTURE.

BY H. CARRINGTON, B.SC. (VICT.), M.SC. (TECH.), A.F.R.A.E.S.

Introduction.

Previous investigations on the effect of moisture on the elastic constants of spruce have been confined to its effect on Young's modulus in the direction of the grain. The most important work in this connection is probably that of H. D. Tiemann,* who deduced curves for pine spruce and chestnut showing that Young's modulus along the grain decreased as the moisture increased up to the fibre saturation point, and that further addition of moisture had little or no effect on the value of the modulus. Tiemann thus found that the modulus decreased to a minimum at the fibre saturation point and then remained nearly constant and independent of any further addition of moisture. The reason for the independence of the modulus on the moisture beyond the fibre saturation point becomes evident if it is considered that when the fibres are saturated, any further moisture added is retained in the cells and in all probability cannot further affect the stiffness and strength of the wood.

It is proposed in this paper to give the results of a series of experiments made to determine the effect of moisture on the elastic constants of spruce, the constants being determined on the assumption that the spruce has three planes of elastic symmetry. Some consideration will also be given to the relation between shrinkage and moisture and to the effect of continued drying on the shrinkage and moisture and consequent possible damage to the cell walls.

Notation.

Let the direction of the grain of the tree be denoted by ZOZ , the direction perpendicular to this and intersecting the axis of the tree by XOX and the direction normal to ZOZ and XOX by YOY . Thus, the direction XOX is normal to the annual layers, and the direction YOY tangential to them. If, therefore, three mutually perpendicular lines be considered lying in the above three directions and intersecting at a point O situated some distance from the pith of the tree, the lines are the intersections of the three mutually perpendicular planes of symmetry OYZ , OZX and OXY at the point.

Corresponding with direct strain, in any one of the three principal directions, three elastic constants will be involved. For direct strain in the direction XOX will cause lateral strain in the directions YOY and ZOZ , and thus involve Young's modulus in the direction XOX and two values of Poisson's ratio corresponding respectively with lateral strain in the directions YOY and ZOZ . Thus, corresponding with the three principal directions there will be three principal values of Young's modulus and six principal values of Poisson's ratio.

Let E_x , E_y and E_z denote Young's modulus in the directions XOX , YOY and ZOZ respectively. Also let σ_{yz} , σ_{zy} , σ_{zx} , σ_{xz} , σ_{xy} and σ_{yx} denote the six values of Poisson's ratio where

$\sigma_{yz} = (\text{lateral strain in the direction } ZOZ) / (\text{longitudinal strain in the direction } YOY).$

Further consideration will show that there are also three principal values of the modulus of rigidity corresponding with shear strain along any of the three pairs of principal planes. Let M_{yz} , M_{zx} and M_{xy} denote these values of the

* U.S. Department of Agriculture, Forest Service Circ. 108, dated August, 1907.

modulus where M_{yz} . . . denotes the modulus of rigidity corresponding with shear strain along the two principal planes OZX and OXY , *i.e.*, along the directions YOY and ZOZ .

The Test Pieces and Experiments.

The specimens were prepared from one of four baulks of spruce obtained from the R.A.E. and representative of the good average spruce which was available for aeroplane manufacture early in the war. The baulks were well seasoned and free from knots and shakes. Typical microphotographs and an end view of one of the baulks have previously been published.* In these publications the baulks were lettered A, B, C and D and the experiments described in this paper were performed on baulk D.

The values of Young's modulus and Poisson's ratio were deduced from flexure experiments. In the case of the determination of E_z and either σ_{zx} or σ_{zy} the test pieces were about 13in. long, 1in. wide and $\frac{1}{4}$ in. thick, and were supported on knife edges 12in. apart, the load being applied to two other knife edges 8in. apart and symmetrical with respect to the outer knife edges. When the load was applied the portion of the beam between the inner knife edges was evidently under a constant bending moment and the constants were determined from measurements of the longitudinal and lateral curvatures over about 1in. lengths situated at the mid-lengths of the beams. When performing an experiment the bending moment was increased by equal amounts at a uniform rate, care being taken not to overstrain the pieces, and readings proportional to the curvature taken after every increase by a reflection method.† In this way two straight lines were constructed, the slopes of which represented the longitudinal and lateral curvatures respectively per unit couple. If the length of the beam was in the direction ZOZ and the width in the direction XOX the experiment yielded values of E_z and σ_{zx} , the latter being given by the ratio of the curvatures. The procedure in the determination of E_x and E_y , and the corresponding values of Poisson's ratio was exactly similar, but the specimens were shorter and their breadths and thicknesses proportionately smaller.

The moduli of rigidity were obtained from torsion experiments on prisms of rectangular cross-section. When a prism with its length in the direction ZOZ and its sides parallel to the two planes of symmetry OYZ and OZX is twisted about its longitudinal axis two values of the modulus are involved, *i.e.*, M_{yz} and M_{zx} and by making the ratio of the sides of the cross-section suitable it is possible to calculate one or other of the moduli with considerable accuracy. If the thickness of the piece is in the direction YOY then M_{zx} can be obtained with an error of less than 0.1 per cent. provided $(\text{breadth}/\text{thickness})\sqrt{(M_{yz}/M_{zx})} > 3$.‡ Since the ratio $\sqrt{(M_{yz}/M_{zx})}$ is approximately unity the breadths and thicknesses of the pieces with their lengths in the direction ZOZ were made about $1\frac{1}{4}$ in. and $\frac{1}{4}$ in. respectively.

The values of M_{xy} were determined in a similar manner. The length of the prism was in the direction XOX and the breadth and thickness in the directions YOY and ZOZ respectively. In order that the error in the value of M_{xy} should be less than 0.1 per cent. then $(\text{breadth}/\text{thickness})\sqrt{(M_{zx}/M_{xy})}$ should be > 3 and since $\sqrt{(M_{zx}/M_{xy})}$ was equal to about 5 then M_{xy} could have been calculated if the cross-sections had been square. The actual dimensions were about 1in. by $\frac{1}{2}$ in. in the directions YOY and ZOZ respectively.

The moduli were deduced from torque twist curves, the twist being measured by the usual reflection method of affixing mirrors to the specimens and using telescopes and scales. More detailed accounts of the methods of determining the

* Phil. Mag., June, 1921, and May, 1922.

† Phil. Mag., Feb., 1921.

‡ Phil. Mag., June, 1921.

constants and the rate of loading the specimens will be found in the Phil. Mag. papers quoted.

Method of Varying the Moisture.

A curve connecting any particular constant with the moisture could have been obtained either by performing experiments on a number of pieces each with a different humidity or by using one piece and varying the humidity between each experiment. The former method was used by Tiemann, but it was decided to adopt the latter in this research in order to avoid the effect of variability in the colotropy of different pieces. Seven pieces were accordingly prepared and seven series of experiments performed, one corresponding with each piece. The pieces were allowed to remain in the laboratory for about one month after preparation before the first experiments were performed. Their humidity was then about 12 per cent. After the first experiments had been carried out the pieces were dried in an electrically heated stove at a temperature of from 100 to 104 degs. C. for from 24 to 48 hours and tested immediately on leaving the stove, and at intervals until they had again absorbed about 12 per cent. of moisture from the atmosphere of the laboratory. They were then placed over water in a sealed vessel at normal temperature and removed for test at intervals. Immersion in water vapour raised the humidity to between 20 and 25 per cent., and in order to increase it well beyond the fibre saturation point the pieces were placed in water. Previous to testing at humidities beyond the fibre saturation point the pieces were suspended in the sealed vessel over water vapour for some time to retard evaporation and thus avoid internal strains and non-uniformity in the distribution of the moisture.

By the above procedure the moisture was varied from nearly zero to well over 100 per cent. and experiments were performed at humidities below the fibre saturation both before and after the pieces had been in water. The percentage moisture was defined in every case as

$$(\text{weight when tested} - \text{weight when dry}) / (\text{weight when dry}) \times 100.$$

Results of Experiments.

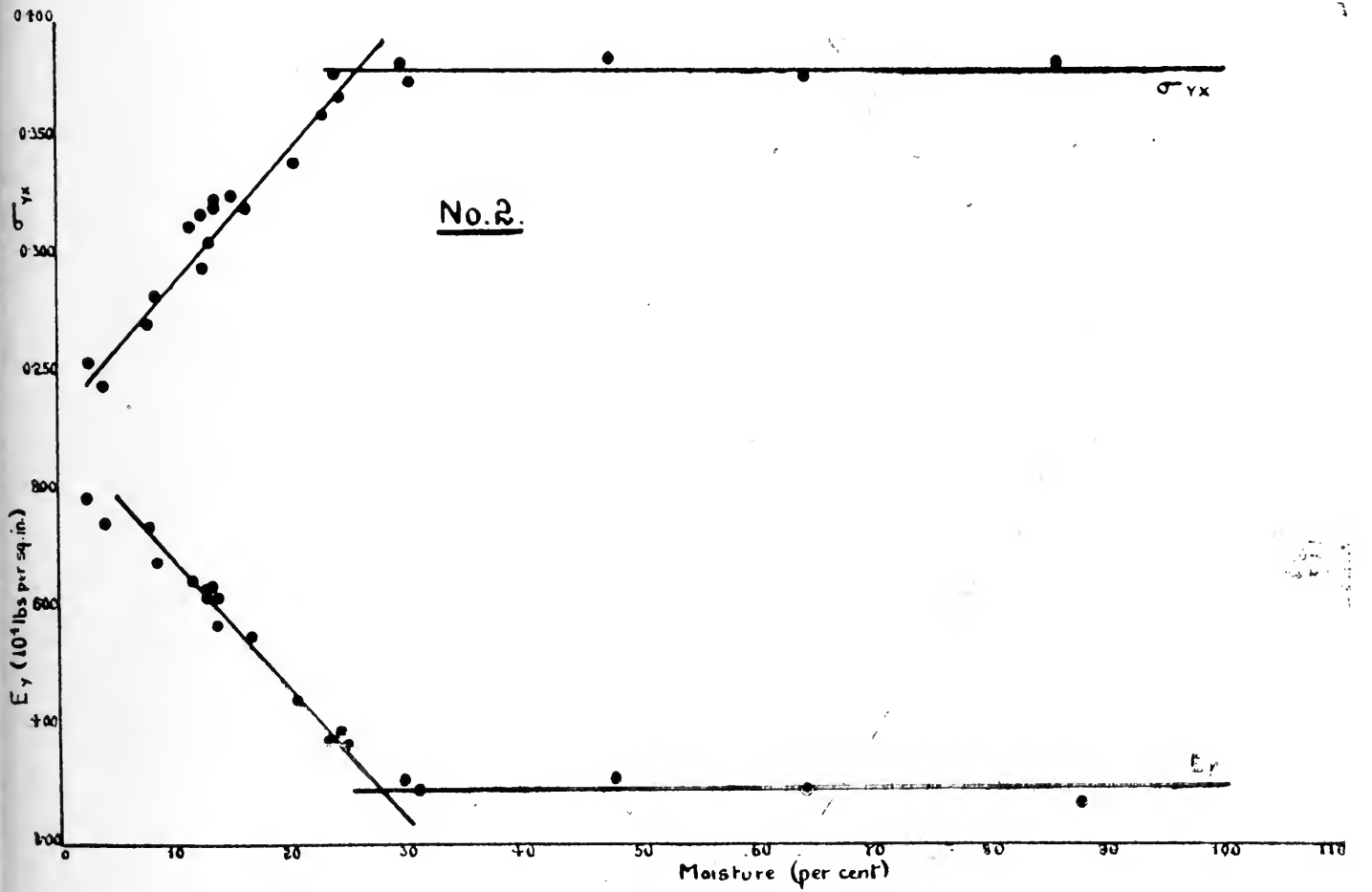
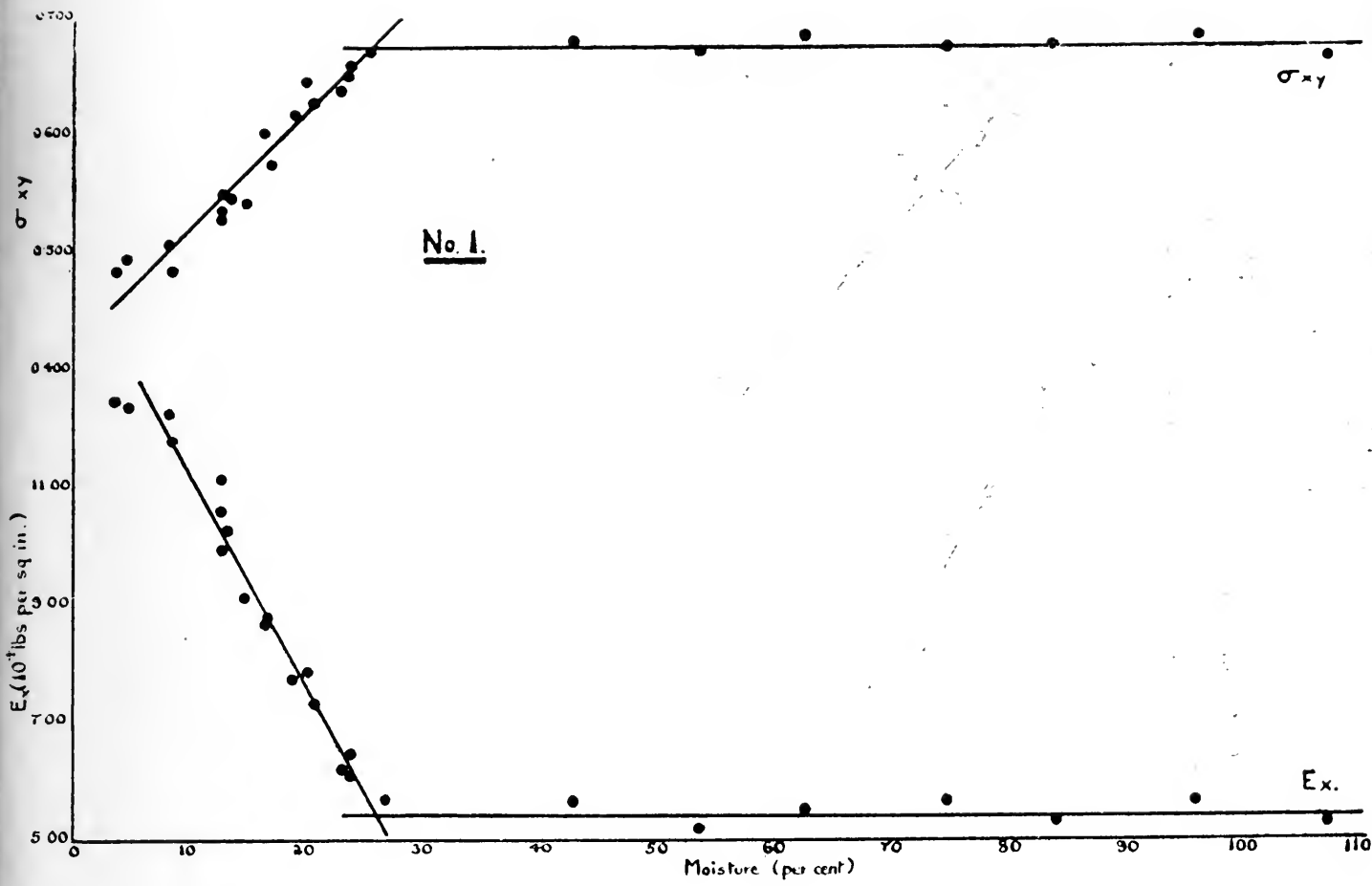
The results of the experiments can be seen by a glance at Figs. Nos. 1 to 6, where each result has been plotted against the corresponding moisture. The points in each case lie approximately on two straight lines which intersect in the region of 30 per cent. of moisture, this being the fibre saturation region of the wood. It will be noted that the constants vary considerably between about 0 and 30 per cent. of moisture, beyond which they remain nearly constant. All the values of Young's modulus, the modulus of rigidity and σ_{zx} decrease from about 0 to 30 per cent. of moisture whilst σ_{xy} , σ_{yx} and σ_{zy} increase within this region.

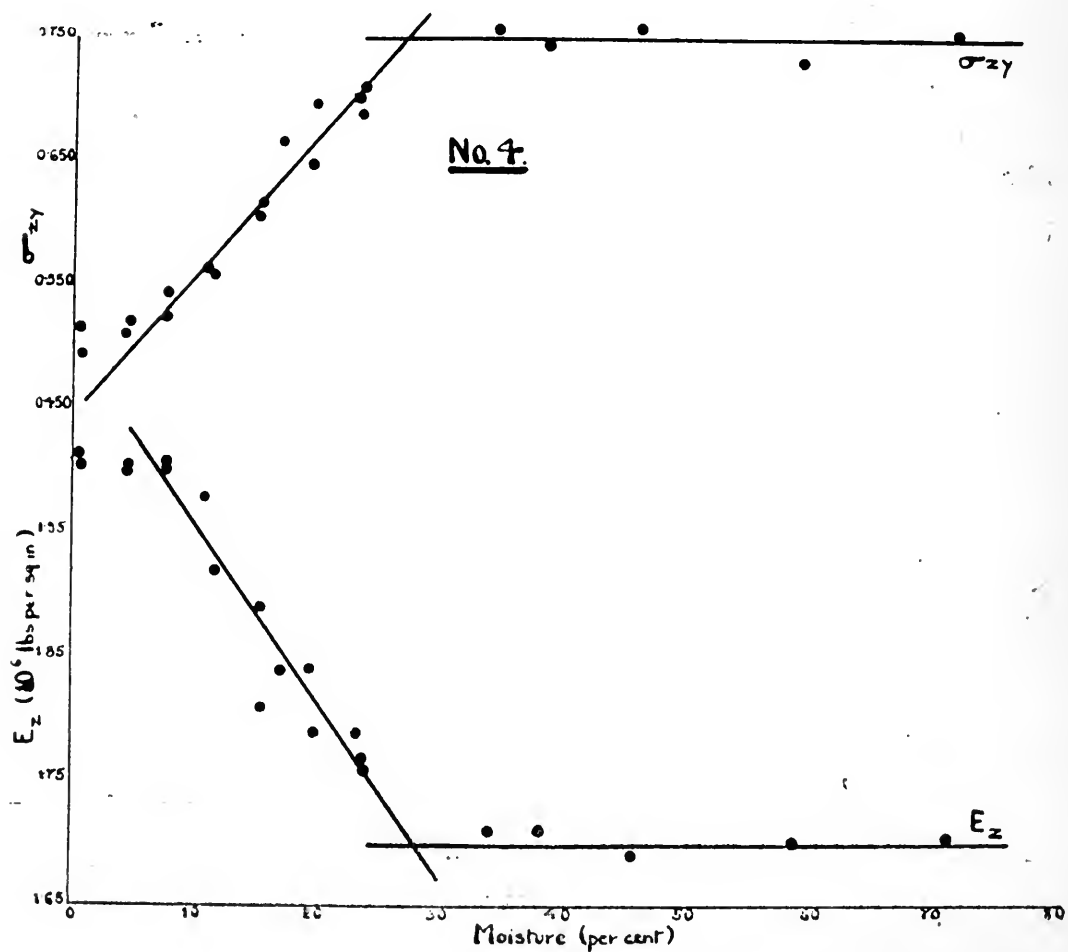
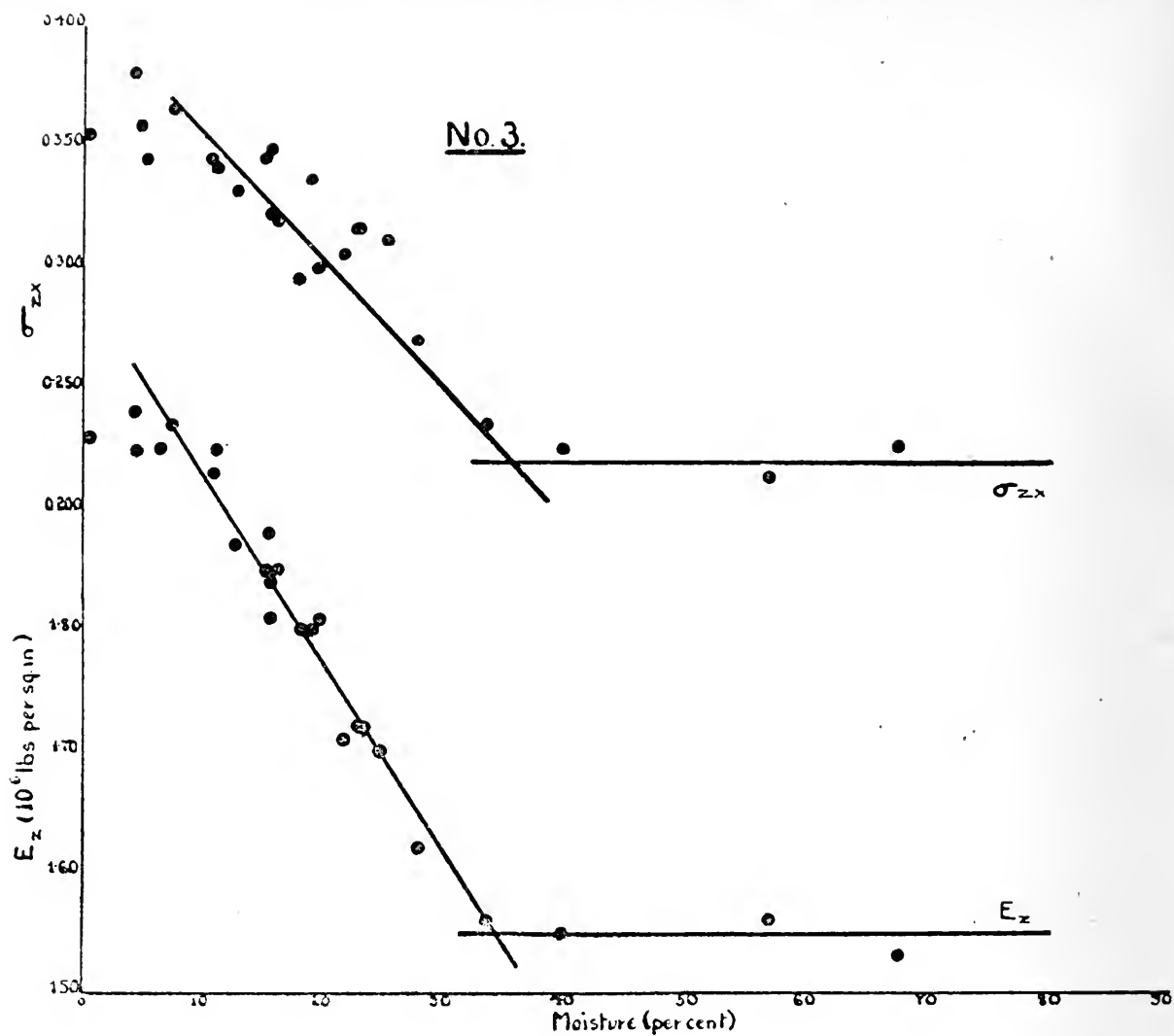
The relation between values of σ_{xz} , σ_{yz} and the percentage moisture are not included. These values are very small, being only about 0.02, and extra precautions during the experiments would have to be taken. Because of this and since the relations could be deduced from the other results the experiments were not undertaken. The relations can be obtained from the three symmetrical equalities

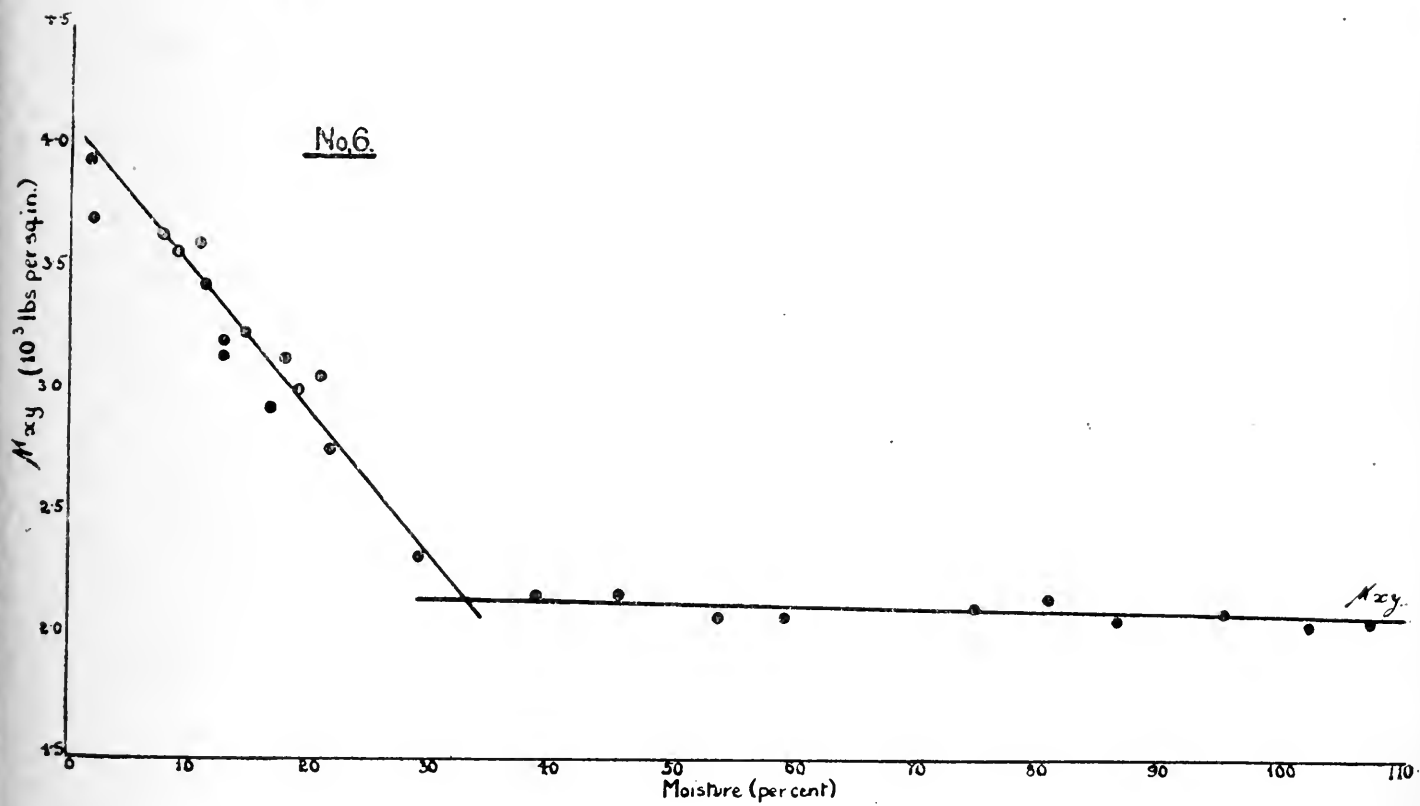
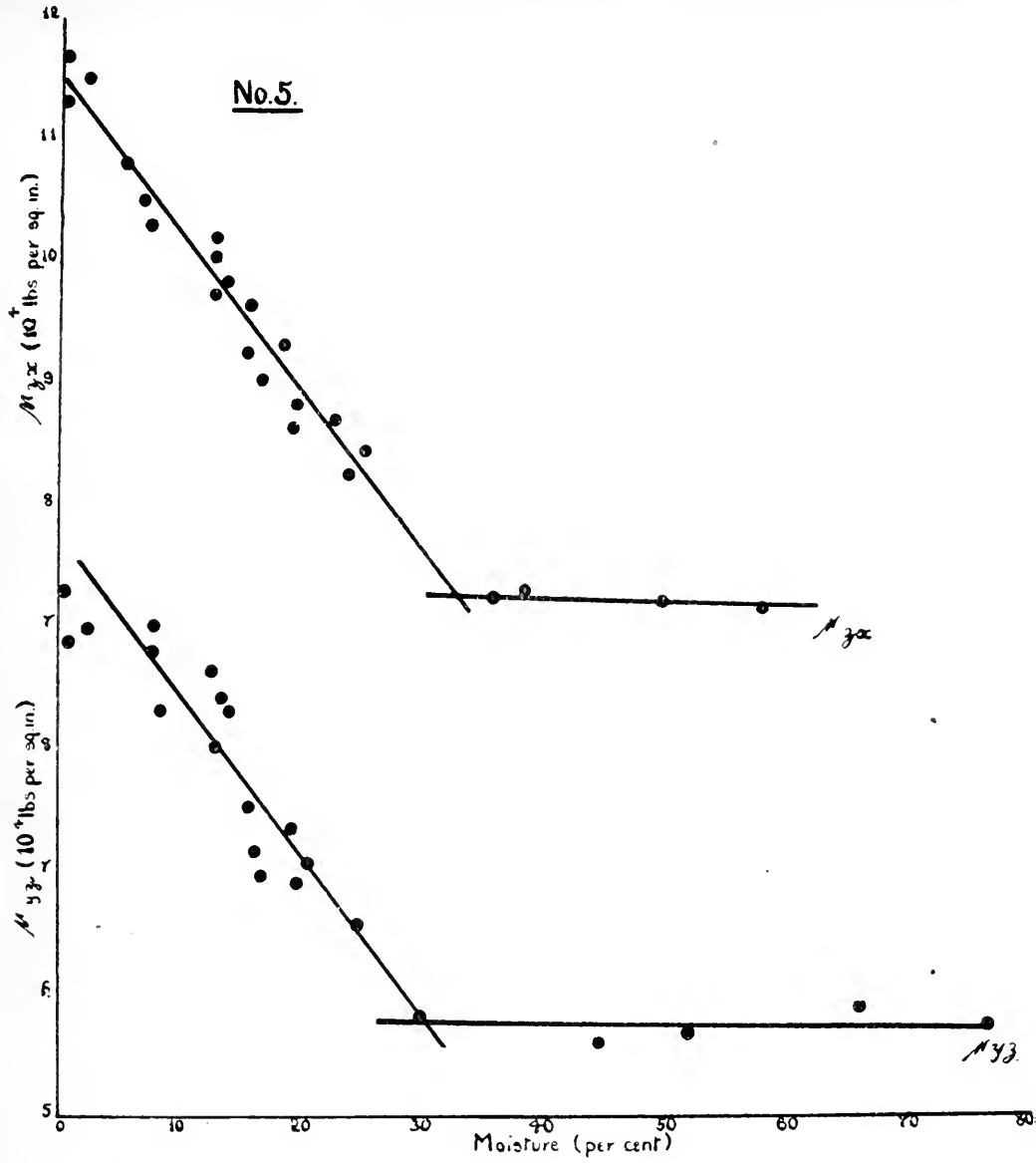
$$E_z/E_y = \sigma_{zy}/\sigma_{yz}, \quad E_z/E_x = \sigma_{zx}/\sigma_{xz}, \quad E_x/E_y = \sigma_{xy}/\sigma_{yx}.$$

These equalities have been shown approximately to hold for spruce containing 12 per cent. of moisture and to be equal respectively to $700 S_y$, $700 S_x$ and S_y/S_x^* where S_y and S_x denote the shrinkages per unit length of dry timber in the directions YOY and XOX respectively, corresponding with 12 per cent. of moisture. In the case of the last of the equalities it will be found from a con-

* Phil. Mag., May, 1922.



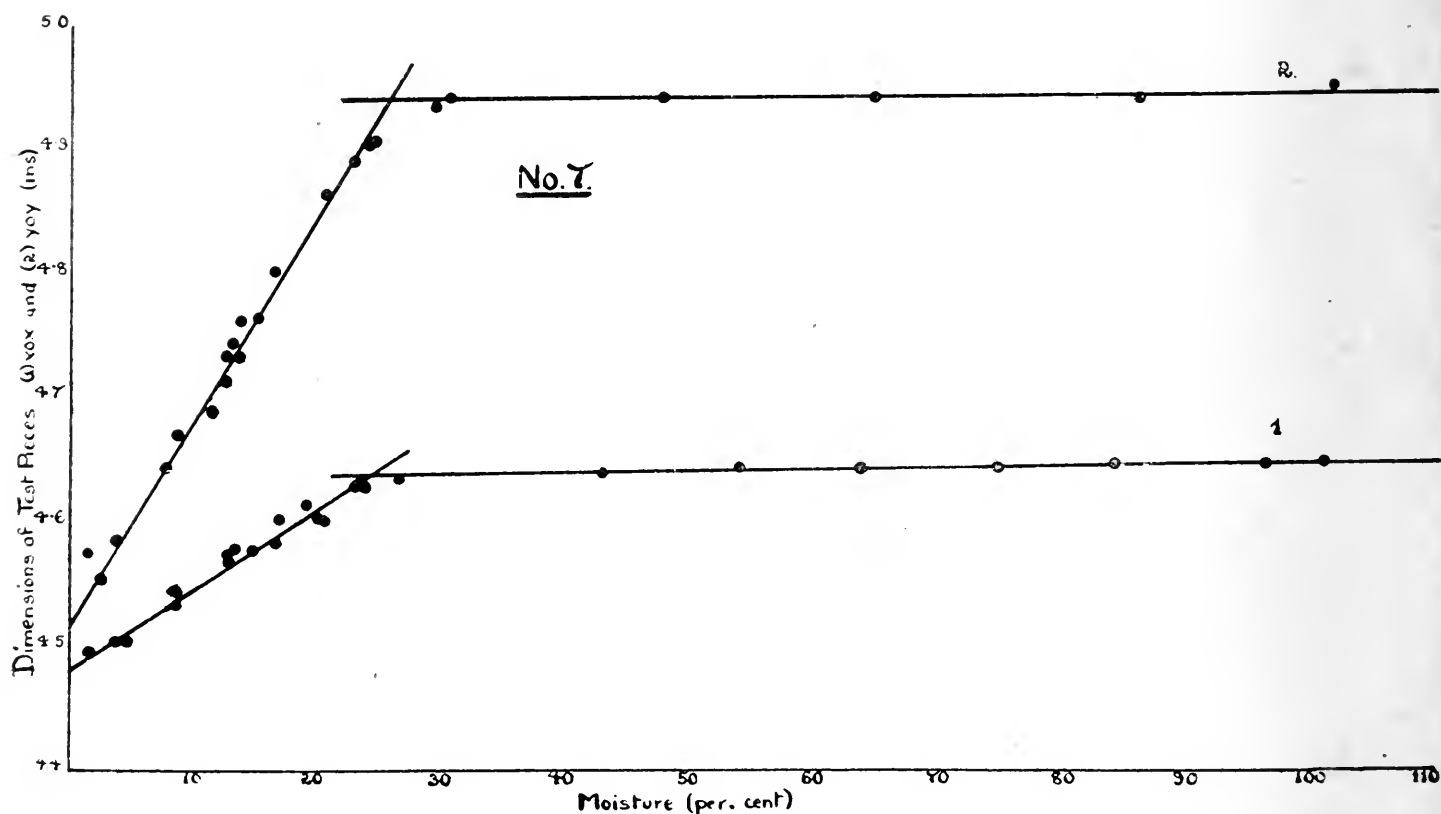




sideration of the curves on Figs. Nos. 1 and 2 that previous to the fibre saturation point $E_x/E_y = 1.63$ and $\sigma_{xy}/\sigma_{yx} = 1.73$ so that the ratios are approximately equal. Assuming the other two equalities to hold, the relations between σ_{yz} and σ_{xz} and the moistures must be similar to those between σ_{zy} and σ_{zx} shown on Figs. 3 and 4.

The relation between E_z and the moisture shown on Figs. 3 and 4 is very similar to that obtained by Tiemann. He, however, finds the relation, between zero moisture and the fibre saturation point, to be best represented by a slightly curved instead of a straight line. This may be due to the fact that in Tiemann's case each plotted value of the modulus corresponding with a particular humidity was the mean of a number of experiments on different pieces and hence the procedure differed from that adopted in this research.

RELATION BETWEEN DIMENSIONS (1)XOX (2)YOY AND MOISTURE



Connection between Shrinkage and Moisture.

In the case of the test pieces corresponding with Figs. 1 and 2 the lengths which were in the directions XOX and YOY respectively were measured immediately after each weighing. The dimensions were then plotted against the corresponding moistures and resulted in the curves shown in Fig. 7. These are strikingly similar to the curves of Figs. 1 to 6 and show that the dimensions increase in a linear manner from dryness to the fibre saturation point and then remain constant. It follows that the relations between the shrinkages defined as (dimensions wet—dimensions dry/dimensions dry) and the moisture must be represented in a similar manner. It further follows that the relation between the shrinkage in volume and moisture must also be similar. For let S_x , S_y and S_v denote the shrinkages in the directions XOX, YOY and in the volume respectively per unit lengths and volumes of dry timber then

$$(1 + S_x)(1 + S_y) = 1 + S_v$$

therefore $S_x + S_y = S_v$ neglecting the small product $S_x S_y$.

The shrinkages in the direction *ZOZ* were very small, being less than 0.1 per cent. at and beyond the fibre saturation point and were accordingly neglected.

Effect of Continued Drying on Dimensions and Weight.

The shrinkages and moisture contents as previously defined are of little value unless the dimensions and weights of the pieces when dry attain to sensibly constant amounts. In order to test this, a number of pieces were prepared and placed in the stove, which was at a temperature of from 100 to 104 degs. C., and weighed and measured at intervals. The results in the case of the moisture are shown in Table 1, and it will be noted that in the case of the large block the moisture increases only slightly. In the case of the small block the increase is greater and the values are not so consistent. This block was however very small, and owing to convection currents and the rapidity with which it absorbed

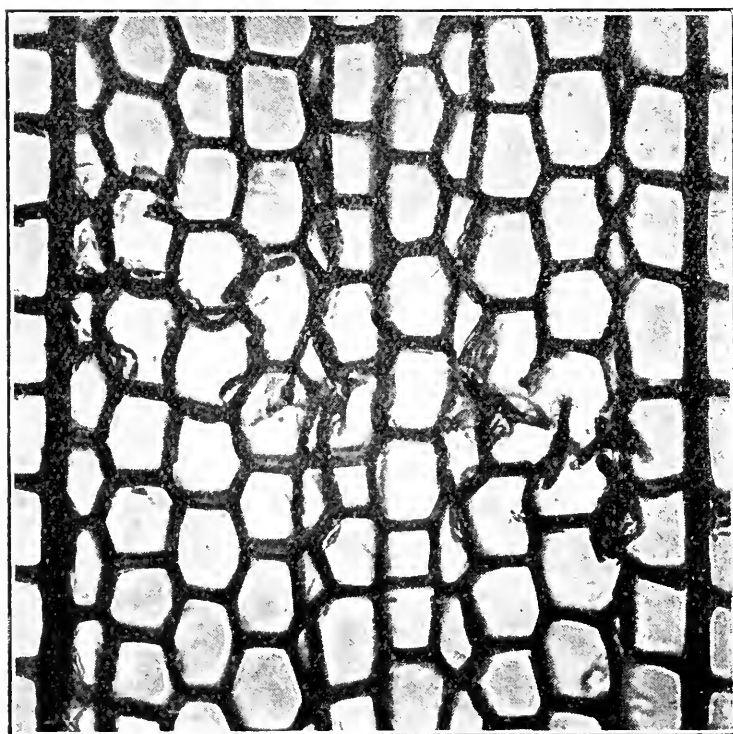


FIG. 8.

moisture from the atmosphere of the laboratory it was difficult to weigh accurately. The increase in the case of the chips and shavings is about the same as for the small block. When considering these increases it is worth noting that cellulose chars slightly at 100 degs. C., and the increase in the case of the small block, the chips and shavings over that of the large block may be due to the greater surface over volume and the consequent greater loss of weight owing to the charring of the proportionately greater surface.

The shrinkages are shown in Tables 2 and 3 and it will be noted that after a lengthy drying the increases are only slight.

From a consideration of the tables it seems reasonable to assume that after pieces of spruce have been dried at 100 degs. to 104 degs. C., for from 24 to 48 hours, they attain to practically constant weights and dimensions so that the shrinkages and moistures are definite properties of the material.

Damage to Cell Walls Due to Drying.

A consideration of some of the curves in Figs. 1 to 6 shows that some of the

points in the region of about 0 and 5 per cent. of moisture depart from the general linearity of the other points. It may at first appear that this is due to rupture of the cell walls during drying and a consequent weakening of the wood. If this had been so, however, the points would very probably have been more scattered than is the case, since each piece was dried at least twice. In order to test the effect of a severe drying on the cell walls a piece was dried at 110 degs. C. for four days and six sections were prepared for examination under the microscope. The cell walls were found to be damaged in the case of one only of the six sections and a photomicrograph of this section magnified about 150 diameters is shown in Fig. 8. Six sections were also prepared from a piece which had not been dried and no ruptures were evidenced in any one of these sections. A photomicrograph of one of them, also magnified about 150 diameters, is shown in

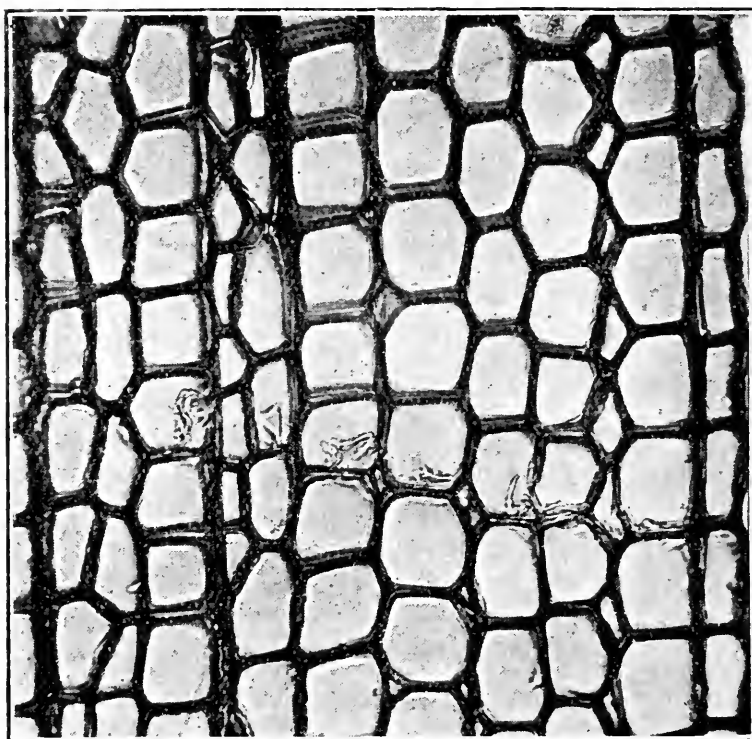


FIG. 9.

Fig. 9. It was therefore concluded that the departure from linearity between 0 and about 5 per cent. of moisture was not caused by damage to the cell walls due to drying.

Tiemann states that "no matter how dried, wood is found upon re-soaking to be weaker than it was originally." The pieces used by Tiemann were, however, generally larger and less homogeneous than those used in this research. If large saturated pieces are dried at 100 degs. C. or over damage to the cell walls will result and will usually be evidenced by the appearance of cracks. As the dimensions of the pieces are reduced and the drying is conducted more carefully a stage appears to be reached when no damage is evidenced. The pieces used in this research were small and the temperature of the stove was raised gradually over a period of a few hours. Pieces which had been wet were allowed to remain in the laboratory until the moisture fell to about 12 per cent. before they were placed in stove and if subsequent tests had to be performed no piece was allowed to remain in the stove for more than 48 hours at one time.

The writer wishes to thank Mr. H. A. Webb, M.A., for many suggestions and for the loan of Tiemann's paper.

TABLE 1.

Time in stove. hrs. mins.	Block. 84.60	Initial weights (grams).		Shavings.
		Block.	Chips.	
		2.223	13.292	14.577
21.20	9.7	9.7	10.2	10.6
46.00	9.6	9.9	10.5	10.7
65.40	9.6	9.7	10.2	10.6
90.50	9.8	10.0	10.3	10.7
112.55	9.8	10.1	10.4	10.8
162.10	9.8	9.8	10.3	10.8
185.20	9.8	9.9	10.4	10.7
257.15	9.8	10.2	10.2	11.1
282.00	9.8	10.3	10.5	10.9
333.20	9.8	10.1	10.6	11.0
357.50	9.9	10.0	10.7	11.1
378.20	9.9	10.4	10.7	11.2
402.25	9.8	10.3	10.3	10.9
449.50	9.9	10.6	10.7	11.2
Moisture (per cent.).				

TABLES 2 and 3.

Length of piece 7.022".

Initial Density of piece 26.4 lbs./cu. ft.

Dimensions (ins.).				Moisture per cent.	Time in stove. hrs. mins.
XOX.	YOY.	S_{xx} 100.	S_{yx} 100.		
1.0162	0.2832	—	—	—	0.0
0.9965	0.2734	1.98	3.60	11.9	46.30
0.9964	0.2733	1.99	3.65	11.9	71.15
0.9965	0.2732	1.98	3.65	12.1	116.25
0.9963	0.2733	2.00	3.65	12.1	214.45
0.9963	0.2731	2.00	3.70	12.2	381.25

Length of piece 0.3022".

Initial Density of piece 25.6 lbs./cu. ft.

Dimensions (ins.).				Moisture per cent.	Time in stove. hrs. mins.
XOX.	YOY.	100 S_x .	100 S_y .		
1.1945	1.5900	—	—	—	0.0
0.9906	1.5343	2.06	3.63	11.9	46.35
0.9898	1.5340	2.07	3.64	12.0	71.20
0.9882	1.5335	2.09	3.68	12.1	116.30
0.9879	1.5330	2.09	3.71	12.2	214.35
0.9872	1.5327	2.10	3.73	12.4	381.30



THE VIBRATION OF AIRSCREW BLADES.

BY CAPT. J. MORRIS, B.A., A.F.R.A.E.S.

1. Airscrews are generally made of wood and owing to the relatively low Young's modulus of timber the blades of an airscrew have a large measure of flexibility. This flexibility is reflected in the comparatively low frequency of vibration of the blades with consequent undesirable effects. Firstly, there is a tendency for the blades to heat resulting in the laminations becoming unstuck, and secondly, there is considerable danger from resonance between the frequency of the blades and the firing impulses of the engine driving the airscrew. The result of this is heating and burning of the boss and ultimately failure of the airscrew. It may even result in failure of the airscrew shaft by shearing.

Airscrews are usually designed to meet certain aerodynamic needs. A certain amount of attention has been given to strength in the ordinary way, but in the opinion of the Author there has not been sufficient consideration of the oscillatory properties of the blades. Usually the question of vibration has been confined to the "flutter," that is to say, the fore and aft vibration of the blades. True, the blades are most flexible in this direction, but they are also flexible in the plane of rotation of the airscrew and it is extremely probable that many cases of failure could be traced to resonance between the frequency of vibration in the plane of rotation and the firing impulses of the engine. The resulting failure—especially if the airscrew shaft fails—might easily be attributed to a defect of the engine when actually it may be that the flexibility of the blades is entirely to blame.

The airscrew, as a rule, is one member of a more or less complex system. Whatever periods of vibration the blades of an airscrew have as a result, it can be shown that, in addition, the blades will have their ordinary periods in free vibration. When arranging for an airscrew for a particular engine the flexible properties of the blades should be known with a view to ascertaining whether these properties will give rise to undesirable effects. Actually the specifications for an airscrew should give a lower limit to the fundamental frequencies of the blades in both the fore and aft plane and the plane of rotation.

2. If a rod (not necessarily uniform in section), encastred at one end, be pulled aside and then let go, so as to oscillate in one plane, then the equation of motion can be shown to be

$$d^2 [EI_x (d^2y/dx^2)]/dx^2 = -\rho (A_x/g) (d^2y/dt^2) \quad (1)$$

where y is the displacement of an element dx at a distance x from the fixed end; A_x is the area of cross section at the element and I_x its moment of inertia for bending; ρ is the density of the material and E its Young's modulus.

If the rod is uniform in section equation (1) becomes

$$EI d^4y/dx^4 = -\rho (A/g) (d^2y/dt^2) \quad (2)$$

This equation can be solved and from its solution we find that the fundamental frequency of vibration of the rod is very approximately the same as if the rod is regarded as light with a concentrated load of one-quarter the weight of the rod at its free end.

Actually the fundamental frequency in transverse vibration will be

$$(1/2\pi) \sqrt{(3EIg/Wl^3)} \quad (3)$$

where W is $\frac{1}{4}$ the weight of the rod and l is its length.

The expression (3) can be written

$$(1/2\pi) \sqrt{(g/Wy_{11})} \quad (4)$$

where

$$y_{11} = l^3/3EI$$

or the deflection due to unit load at the free end. If the rod is not uniform in section and y_{11} is the deflection due to unit load at the free end, there will be an equivalent tip load W , dependent on the shape of the rod, such that the fundamental frequency will still be given by the formula (4). There are well known experimental methods for finding both y_{11} and W .

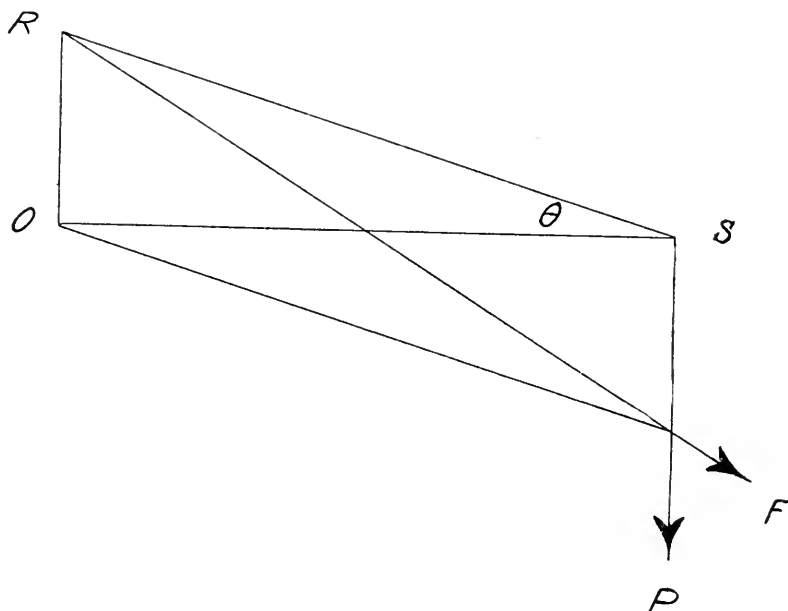


FIG. 1.

3. Airscrew blades, in addition to other forces, are subjected to centrifugal force. In order to investigate the effect of this force consider a light cantilever subjected to, at its free end, a load P at right angles to its normal line and a lateral load F (see Fig. 1).

Let OS be the normal line of the cantilever and let OR and PS be perpendicular to this line. Let RF be the line of action of F and SP the line of action of P ; and let angle $RSO = \theta$.

If y_{11} and ϕ_{11} are the deflection and slope at the free end due to unit load alone, F being zero, it can be shown that the deflection and slope respectively when P and F both act as in Fig. 1 are

$$(P + F\theta) \gamma(a) y_{11} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and

$$(P + F\theta) \Phi(a) \phi_{11} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where

$$\gamma(a) = 3(a \coth a - 1)/a^2 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and

$$\Phi(a) = (\tanh \frac{1}{2} a) / \frac{1}{2} a \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$a \text{ being } \sqrt{(Fl^2/EI)} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

When a is small $\gamma(a)$ and $\Phi(a)$ are both practically unity and they do not differ appreciably from unity when a is as large as one radian.

4. Suppose F arises from the centrifugal force of a load W then

$$Fl^2/EI = Wl^3\Omega^2/EIg \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where Ω is the angular velocity of rotation.

Suppose (10) is small then $\gamma(a)$ and $\Phi(a)$ can each be taken as unity. Two special cases arise.

(1) The line of action of F passes through O (this will be the case for the

vibration of the airscrew blades in the plane of rotation) so that $\theta = 0$. Under these conditions the deflection and slope respectively become

$$Py_{11} \text{ and } P\phi_{11}$$

so that the effect of the centrifugal force on the bending of the cantilever is negligible.

(2) The line of action of F is parallel to the normal line of the cantilever (this will be the case for vibration of the airscrew blades in a fore and aft plane).

In this case $\theta = -\gamma/a$ where γ is the deflection at the free end of the cantilever.

We find in this case

$$\gamma = Py_{11}/(1 + W\Omega^2 y_{11}/g) \quad (11)$$

and for the slope

$$\Phi = P\phi_{11}/(1 + W\Omega^2 y_{11}/g) \quad (12)$$

5. Consider next the frequency of the "flutter" or fore and aft oscillations of the airscrew blades.

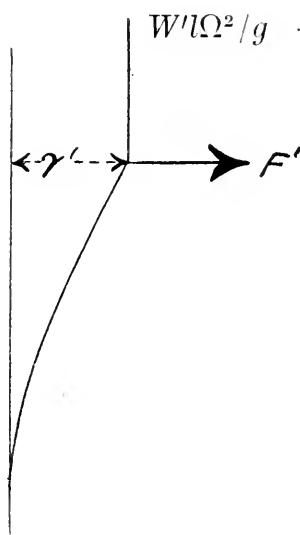


FIG. 2.

Let W' be the equivalent tip load and y'_{11} the equivalent coefficient of deflection. F' is the equivalent tip air force (see Fig. 2).

Having regard to the effect of the centrifugal force in this case, by the application of formula (11), we have for the equation of motion of W'

$$(1 + W'\Omega^2 y'_{11}/g) \gamma' = (F' - W'\ddot{\gamma}'/g) y'_{11} \quad (13)$$

or

$$[(W'y'_{11}/g)(D^2 + \Omega^2) + 1] \gamma' = F'y'_{11} \quad (14)$$

Thus the frequency of vibration is given by

$$(1/2\pi) \sqrt{(g/W'y'_{11} + \Omega^2)} \quad (15)$$

In this case the frequency of vibration is affected by the centrifugal force; the extent may be considerable and is dependent on the relative values of $g/W'y'_{11}$ and Ω^2 .

6. Take next the motion in the plane of rotation of the airscrew (see Fig. 3).

Let θ be the angular displacement of the normal line of the airscrew blades and let γ_1, γ_2 be the displacements of conjugate elements of each of the two blades, each at a distance x from the centre of the airscrew.

We have for the equations of motion

$$d^2 (EI_x d^2 \gamma_1 / dx^2) / dx^2 = -F_1 - (\rho A_x / g) (d^2 \gamma_1 / dt^2 + x d^2 \theta / dt^2) \quad (16)$$

and

$$d^2 (EI_x d^2 \gamma_2 / dx^2) / dx^2 = -F_2 - (\rho A_x / g) (d^2 \gamma_2 / dt^2 + x d^2 \theta / dt^2) \quad (17)$$

where F_1 , F_2 are the corresponding air loadings at the points, and the centrifugal forces have been neglected in accordance with case (1) in paragraph 4.

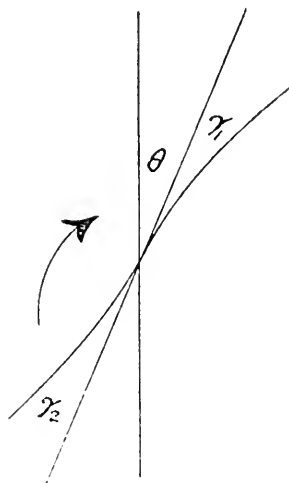


FIG. 3.

Thus

$$d^2 (EI_x d^2 \gamma / dx^2) / dx^2 = -(\rho A_x / g) d^2 \gamma / dt^2 \quad (18)$$

where

$$\gamma = \gamma_1 - \gamma_2$$

and

$$F_1 - F_2 = 0$$

But (18) is the equation for the free vibration of one blade regarded as a cantilever and this has been considered in paragraph 2.

Thus the blades will have, in addition to any other frequencies, their ordinary period for vibration in their plane of rotation.

In addition to giving rise to the frequencies considered, the flexibility of the blades in the plane of rotation may have an appreciable influence in lowering the speed of torsional resonance of the crankshaft, but this aspect is beyond the scope of the present investigation.



SCOTTISH BRANCH.

THIRD ANNUAL REPORT FOR YEAR ENDING 31st MAY, 1922.

The Executive Committee have pleasure in submitting the Third Annual Report of the activities of the Scottish branch of the Society.

A reduction in the number of members is no doubt due to the fact that aeronautical science is not receiving in this country the enthusiastic consideration which its importance deserves.

The following is the programme of lectures delivered during the Session 1921-22 :—

On 19th September a communication was read from Mr. Norman A. Yarrow, of Victoria, British Columbia, on "Civil Aviation in Canada." The Right Hon. Lord Weir of Eastwood presided.

On 17th October a lecture was delivered by Col. V. C. Richmond, of the Airship Dept. of the Directorate of Research, on "The Organisation of a Colonial Airship Service." Mr. A. J. Campbell presided.

From 3rd to 8th October a series of lectures was given by Sir Ross and Sir Keith Smith in Hengler's Circus, on their Flight to Australia, illustrated by kinema views. The chair was occupied on six successive evenings by the following :—Monday, the Right Hon. the Lord Provost; Tuesday, the Right Hon. Lord Weir of Eastwood; Wednesday, Sir W. F. Russell, Chairman of the Chamber of Commerce; Thursday, Mr. W. Gillies, LL.D., Pres. of the Royal Philosophical Society; Friday, Mr. Harold Yarrow, Chairman of the Institute of Engineers and Shipbuilders. These lectures were attended by audiences ranging from 800 on 3rd October to 1,300 on Saturday evening, 8th October.

On 31st October a lecture was delivered in the Natural Philosophy Class-room of the University by Professor Gordon Gray, on "Research Work and the Application of Gyroscopes to Aviation." Mr. James G. Weir, C.M.G., presided and there was an audience of nearly 200.

On Monday, 14th November, a lecture was delivered in the Engineers' Institute by Air-Marshal Sir Hugh Trenchard, Bart., C.B., K.C.B., Chief of the Air Staff, on "Aids to an Auxiliary Air Force." The Right Hon. Lord Weir of Eastwood presided.

On Wednesday, 7th December, a meeting of the ex-Airmen and Students' Section was held in the University when a paper was read by Mr. C. R. Catesby, on "Flying in 1921."

On Monday, 12th December, 1921, a lecture was delivered in the Technical College by Col. Gold, of the Meteorological Dept. of the Air Ministry, on "The Application of Meteorology to Aviation." The lecture was illustrated by lantern slides and Professor Mellanby presided.

On 25th January a lecture was given in the University to the ex-Airmen's and Students' Section by Major Cleghorn, B.Sc., on "Aeroplane Repairs During War Time."

On 27th February a lecture was delivered in the Technical College by Mr. Alan E. L. Chorlton, C.B.E., M.Inst.C.E., M.I.Mech.E., on "Special Light Weight Engines." There was an attendance of over 300 and Professor Mellanby presided.

On Monday, 10th April, the annual lecture to the Cadets of the Public Schools of Glasgow was delivered by Major D. C. M. Hume, of the Seaplane Research Dept. of the Air Ministry, in the large hall of the Engineers' Institute, on "Boats that Fly." The hall was completely filled by the Cadets in uniform of the leading Public Schools, the audience numbering over 300. The lecture was illustrated by limelight views. Major Cleghorn presided and a cordial vote of thanks was accorded to the lecturer on the motion of Mr. Harold E. Yarrow.

Work Among the Students.

This most important work has proceeded in a satisfactory manner during the past session. On Friday, 21st October, the Hon. Secretary addressed Professor Mellanby's third year class, the number present being 80, of whom 20 filled up the form for student membership.

On 24th October Professor Mellanby's second year class numbered 130, of whom 17 filled up forms for student membership.

On 26th October Professor Cormack's third and fourth year classes were addressed, at each of which 180 were present. The combined adhesions from both classes was 71.

On 27th October Professor Andrew Gray's Natural Philosophy Class was addressed, at which 200 were present, and the number of adhesions was 21.

On the same date, at a later hour, Professor Gordon Gray's Nos. 1 and 2 classes were addressed, at each of which 200 were present. The number of adhesions from both classes was 85.

In this way over 1,000 engineering students were addressed and the literature of the Society was forwarded to those signifying their special interest, numbering in all 214.

This work among the students the executive regards as of the utmost importance and they consider it as a work which will rapidly develop.

In regard to finance the position is as follows:—The annual subscriptions received amount to £222 2s. 8d., compared with £231 1s. od. last year. There have been no grants from the Universities and therefore a diminished amount has been paid for lectures. The ordinary expenses, owing to this and other causes, have dropped from £485 3s. 5d. to £340 18s. od. The balance now in hand from the Initial Establishment Account is about £400. This amount it is intended to spread over at least two years, and before it is finally expended it is hoped that aeronautical science will have come to its own, and that the number of new members joining the Society will be sufficient to make the income meet the moderate expense which is needed to keep the Society in that state of vigour which is so important for the work in Scotland in view of the large number of engineering students in the University, with whom the Society is keeping in close touch at considerable cost.



THE ROYAL AERONAUTICAL

Abstract of Cash Receipts and Payments

RECEIPTS.

	£	s.	d.	£	s.	d.
Cash in Bank on Temporary Loan less due to Hon. Secretary at 1st June, 1921				529	10	6

ORDINARY.

Annual Subscriptions received from 1st June, 1921	222	2	8			
Refund of Income Tax	3	16	0			
	<hr/>			225	18	8

EXTRAORDINARY.

Special Donations	10	10	0			
Special Donation to Initial Establishment Fund ...	5	0	0			
Interest on Corporation Mortgage less Tax ...	15	16	2			
Part Proceeds from Ross-Smith Lectures ...	13	1	8			
	<hr/>			44	7	10

£799 17 0

GLASGOW, 7th July, 1922

SOCIETY (SCOTTISH BRANCH).

for the year ended 31st May, 1922.

EXPENDITURE.

	£	s.	d.	£	s.	d.
Amount paid to Head Office, London, being one half of Annual Subscriptions received by this Branch from 1st June, 1921, to 16th Dec., 1921, as per arrangement	45	11	0			
Miscellaneous Expenses <i>re</i> Lectures, less Contributions received	58	19	0			
Printing	4	10	8			
Typewriting Supplies, Stationery, etc.	14	13	10			
Postages, Telegrams and Trunk Calls	20	2	0			
Advertising	3	1	0			

HON. SECRETARY'S EXPENSES—

(1) Travelling Expenses	£3	3	0			
(2) Clerical Assistance	85	2	6			
(3) Allowance for use of Office and Staff, Typewriters and Sundry Expenses from 1st June, 1921, to 31st May, 1922	105	15	0			
				194	0	6
						340 18 0

Balance of Funds on hand made up as follows:—

Cash in Bank	33	13	6			
On Deposit Receipt	100	0	0			
On Loan with Glasgow Corporation	300	0	0			
In hands of Hon. Secretary	25	5	6			
				458	19	0
						£799 17 0

Audited and found correct.

(Sgd.) J. WYLLIE GUILD & BALLANTINE, C.A., Auditors.

PROCEEDINGS.

FOURTH MEETING, 59th SESSION.

An Ordinary General Meeting of the Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 16th, 1922, the Chairman, Professor L. Bairstow, in the chair, when a lecture was delivered by Mr. R. McKinnon Wood on "The Co-relation of Model and Full Scale Work."

The CHAIRMAN, in calling upon Mr. McKinnon Wood to read his paper, said that Mr. Wood was in a particularly advantageous position to deal with this subject, since for very many years he had been in charge of full scale experimental work in aerodynamics at the Royal Aircraft Establishment and, in addition, had had at his disposal wind channels for the carrying out of model work. The greater part of the model work in this country was done at the National Physical Laboratory, and with the members of the staff of the National Physical Laboratory Mr. Wood was on intimate terms. They visited each other's establishments and occasionally exchanged members, so that both sides of the subject, the full scale and the model work, were known to Mr. Wood at first hand. In the past the subject had been an extremely controversial one, one of the controversialists being himself, but he was glad to say that in many respects the controversy had now gone out of the subject, although that did not in any sense mean that the interest had gone out of it. They were realising that in very many ways new problems were turning up. The simpler theories with which they began aeronautics were gradually giving way to more complex ones, and the rules to which they had tied their faith in the early days of aeronautics, and which were considered complete, were now known to be somewhat incomplete. That was a tribute in itself to those people who were working on aeronautics. They were willing to see new moves and to develop gradually from main principles without in any sense stating that those main principles were to be thrown overboard. He then asked Mr. McKinnon Wood to give them an account of the present position of and knowledge as to the relation between model and full scale experiments.

Mr. McKINNON WOOD then read his paper.

THE CO-RELATION OF MODEL AND FULL SCALE WORK.

Introductory.

Model tests are capable of a wide usefulness in aeronautical engineering if the model work can be satisfactorily co-related with the full scale; and they have, in fact, played a very important part. They provide a rapid and economic method of testing new ideas and investigating aerodynamic theories; of discovering the best form for wing sections, fuselages, airship hulls, etc., and of guiding the designer of aircraft in obtaining the best proportions and distribution of the component parts of the craft in order to attain speed, climb, stability, and ease of control. Many designing firms make use of wind channels, and work is also carried out at the National Physical Laboratory and the Royal Aircraft Establishment directly to aid designers. I believe that a fuller use of wind channels for design purposes could be made with advantage and that their value will be greatly extended when the testing of models with the airscrew running has become a matter of routine. This is not prohibitively difficult or costly. The action of the airscrew is important in its effects upon trim and stability and in producing

a tendency to turn, effects which one may guess but cannot calculate with any certainty.

May I give two illustrations of the value of the model in design? In one case in my experience the climb of a new aeroplane was found to be considerably poorer than was expected in view of the power, weight, and wing area, and wind-channel tests carried out after the aeroplane had been built and flown showed that the poor performance could have been predicted. In another case an aeroplane in service acquired considerable unpopularity on account of its tendency to turn when the engine was opened out. This could have been predicted from a wind channel test, in this case of a somewhat elaborate nature.

We cannot calculate the lift or drag of a wing or the centre of pressure or the angle of downwash behind it, the thrust or torque of an airscrew, the drag of fuselage or other parts, the mutual interaction of airscrew and fuselage. The only data upon which we can base design is that derived from model or full scale experiments. We can piece such data together and so build up the complete aircraft, as we calculate the thrust and torque of an airscrew from aerofoil data or the drag of a complete aeroplane from component parts; but the validity of such a calculation requires experimental confirmation. Our experimental data can be acquired much more rapidly, safely and economically by model tests than by full scale work. The subject of this paper is the "if" of my first sentence: If model work can be satisfactorily re-related with the full scale. Unless we can establish some relation between the model work and the full scale, our model work must be of very uncertain value. We may endeavour to do this theoretically or experimentally, and I shall start with the theoretical aspect of the question.

Theory.

Aircraft moves in a medium possessing the following physical properties :—

- (1) Fluidity—the property that, when the fluid is at rest, the stress over an elemental surface is normal to it.
- (2) Viscosity—the property of resistance to a shearing motion, which introduces tangential stress when part of the fluid is in motion relative to a neighbouring part.
- (3) Compressibility—the density varies, directly as the pressure and inversely as the temperature.

Excluding very fast-moving bodies such as shells, bombs and airscrew blades, we may regard air as incompressible, as the variations of pressure produced by bodies moving at the speed of aircraft are not large enough to cause important changes of density.

The important properties in most aeronautical work are the fluidity and the viscosity, and it will be shown later that, although viscosity is an essential property in all aerodynamic problems, these problems may frequently be divided into two parts, in one of which it is reasonable to suppose that viscosity plays an insignificant part.

The branch of mathematics known as hydrodynamics deals chiefly with fluids possessing only the first property—fluidity. In such a fluid the relation between model and full scale would be simple and definite. The pressure at any point on a body would be proportional to :—

- (1) The density of the fluid (ρ).
- (2) The square of the speed of motion through the fluid (V) or in mathematical symbols

$$p = k\rho v^2 \text{ where } k \text{ is a constant.}$$

In any actual fluid the viscosity must enter into this equation. Experiment

has shown that the viscous couples are proportional to the rate of shearing and a consideration of the dimensions of the coefficient of viscosity shows that it must enter into the equation :—

$$p = k\rho v^2$$

in the form

$$k = f(vl\rho/\mu)$$

where μ is the coefficient of viscosity and l a linear dimension of the model.

The equation expresses the Law of Dynamic Similarity for a viscous incompressible fluid. Expressed in words, it states that the pressure at corresponding points full scale and model will be in the ratio of the corresponding values of ρv^2 if the value of $vl\rho/\mu$ is the same; but provides no indication of the manner in which the pressure may vary if this quantity is different.

In order to conform to this law we should require to test a one-tenth scale model at ten times the full scale speed. This would require a very great expenditure of power and necessitate measuring very large forces; but apart from this, the results would be vitiated by the air ceasing to be virtually incompressible under the high pressures which would occur at such speeds.

This Law of Dynamic Similarity cannot therefore be conformed to in the wind channel as we use it. But there is another possible method by which models might be tested at the full scale value of $vl\rho/\mu$. If a model to a scale of 1/10 be tested in a channel built inside a strong steel chamber filled with air at 10 atmospheres pressure at atmospheric temperature, the value of $vl\rho/\mu$ is the same as that of the full scale at the same speed. The forces to be measured will be ten times as great per unit area as on the full scale, and this introduces difficulties in supporting the model which would make it desirable to work at lower velocities with a compensating increase in density and so reduce the forces to convenient values. I believe that the not inconsiderable difficulties which would arise in constructing a high pressure channel and designing suitable balances can be overcome. The cost of this method of experimenting would be greater than that of an atmospheric channel, but still much less than that of full scale work. The high pressure channel, however, belongs to the future, and my concern is here with the use of present apparatus.

Variation of the coefficient k in the equation

$$p = k\rho v^2$$

as we vary the size of the model has been called a "scale effect," and we have seen that the same variation should be produced by increasing the scale, the speed or the density of the fluid or by decreasing the viscosity in the same proportion.

Discussion of the nature of viscous flow may conveniently be started by considering the flow past a body consisting only of a surface moving in its own plane. The layer of fluid in immediate contact with the solid surface is agreed to be at rest relative to the surface, and the velocity builds up as we pass outwards from it. On the assumption that the flow is steady laminar flow the velocity gradient and the drag exerted on the surface can be calculated. The drag is proportional to the speed. Experiments with fluids passing down pipes of small bore at low speeds have given the calculated value of the resistance, but at higher speeds it was found that the resistance increased more nearly as the square of the speeds. It was also shown by introducing a filament of coloured liquid into water flowing along a glass tube that the flow was steady over the range of speeds for which the resistance varied as the speed, and became turbulent when the law of resistance changed. The state of steady flow occurs, however, only at very low values of $vl\rho/\mu$, and the values with which we are concerned in aeronautics are well inside the range of turbulent flow.

The resistance of thin smooth flat plates edge-on to the wind has been found by experiment to follow the law

$$k = (vl\rho/\mu)^{-0.15}$$

over a wide range.

We are generally concerned with bodies of some thickness whose drag is composed of two parts:—

- (1) The resultant of the pressures normal to its surface.
- (2) The resultant of the pressures tangential to its surface.

The distribution of pressure over bodies such as airship hulls can be calculated for the case of an inviscid fluid, and the results have been compared in some cases with measurements made upon a model. The agreement of calculated and measured values is very close over the nose, but they differ widely at the tail. The calculated values have no resultant, but the measured values integrate to give a drag force. The effect of viscosity is therefore two-fold:—

- (1) It modifies the form of the flow so that the normal pressures have a resultant.
- (2) Tangential forces are exerted on the body.

The resultant drag is composed of these two parts in proportions depending upon the shape of the body. Photographs of the flow round fair-shaped bodies indicate that the streamlines do not follow the body to the extreme tail, but break away from the body at a greater or less distance, according to the fineness of the body and enclose a "dead water" region. The pressure therefore fails to build up to the "pitot" value, $\frac{1}{2}\rho v^2$, which occurs at both ends in the calculated values for non-viscous flow, and a resultant force is produced. The part of the drag due to the normal pressures is commonly greater than that due to the tangential forces, and it is evident that scale effect upon drag is not confined to the component due to the tangential forces.

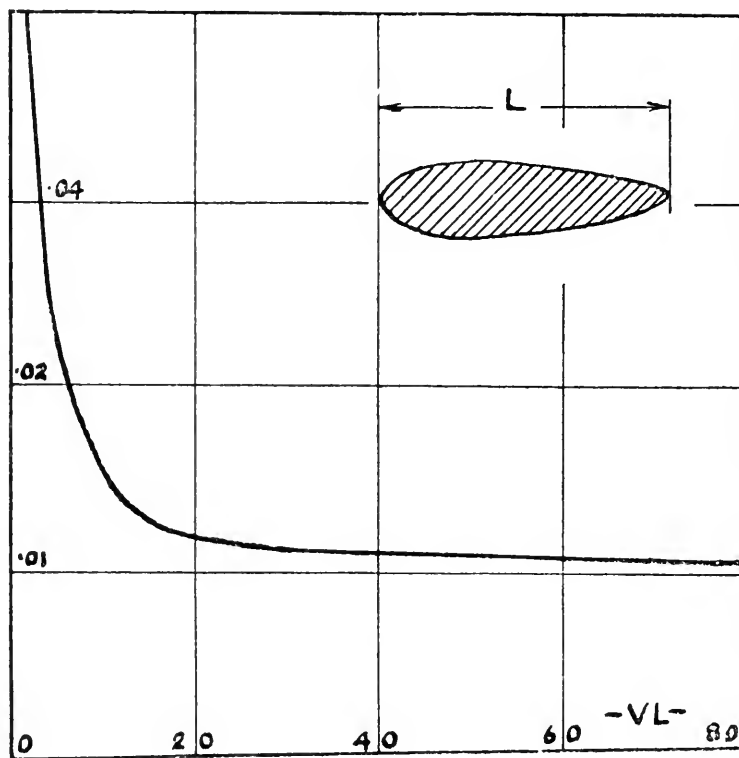


FIG. 1.

*Drag per unit length of an aeroplane strut divided by $\rho L V^2$
showing the variation with VL/μ .*

I reproduce a curve obtained in a wind channel showing the scale effect upon the drag of a fine shaped body (an aeroplane strut). The scale effect is large at the lower values of $vl\rho/\mu$, but is quite small at the high values. This particular case is typical of results obtained with similar forms of bodies and we conclude

that, while experiments upon small models at low speeds may be of little value, it may be possible to carry out model tests at sufficiently high values of vl to give a close approximation to the full scale.

So far we have considered only symmetrical bodies moving along their axes or planes of symmetry. A body which is not symmetrical with respect to the direction of its motion experiences both a drag and a cross wind force or lift. The mean pressure of the air is less on one side than on the other and the velocity is greater. The principle of conservation of energy leads to Bernoulli's equation connecting pressure and velocity:—

$$p + \frac{1}{2}\rho v^2 = \text{const.}$$

except to the extent to which energy is degraded into eddies and heat by the action of the viscous forces. This degradation of energy is small if the drag is small in comparison with the lift, and Bernoulli's equation is closely true for the streamlines which do not pass very close to the surface of a wing. In the language of hydrodynamics, the flow is composed of a translation (or linear motion) and a circulation round the wing. It can be shown that the existence of tangential stress in the fluid is essential for the production by a wing of a circulation round it. Lift is therefore dependent, as drag is dependent, upon the action of viscosity.

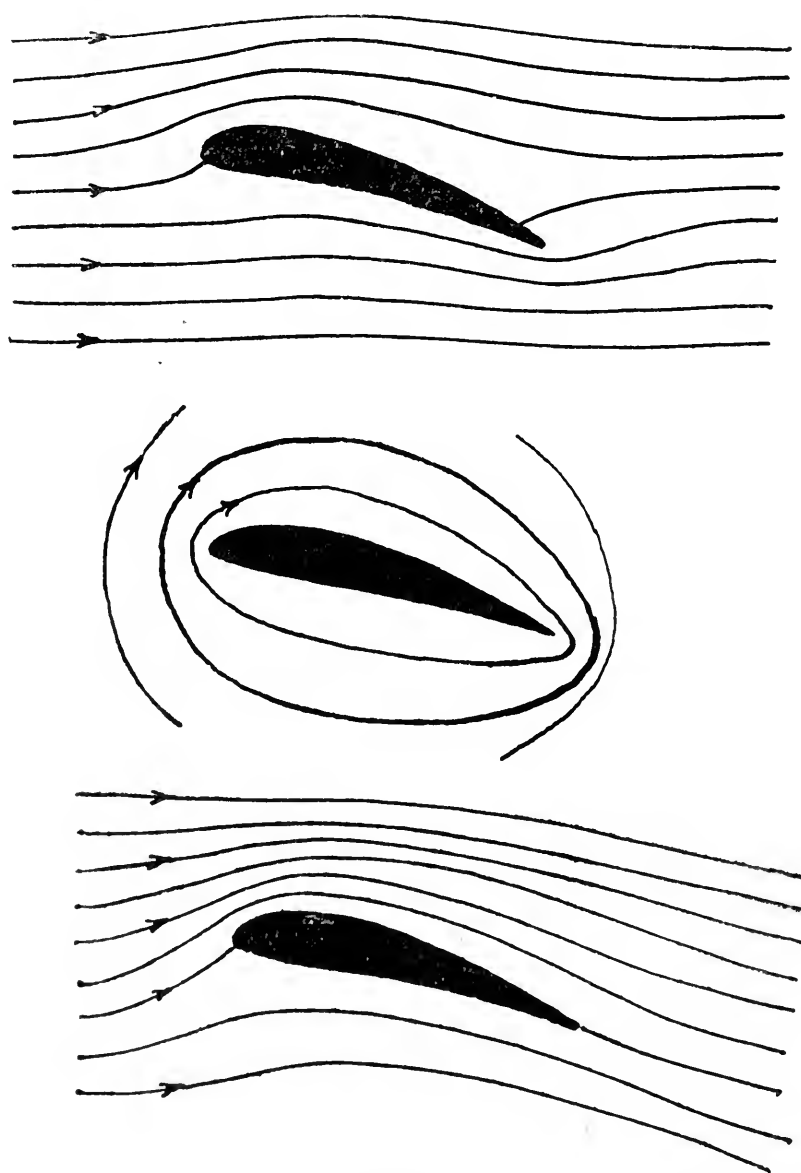


FIG. 2.

Diagram 1 shows the form of flow which should theoretically exist past a wing moving in a fluid having no viscosity, the wing being supposed to extend indefinitely in either direction across the stream so that the flow is two-dimensional. Diagram 2 shows the fluid circulating round a wing. In both cases the form of the streamlines is quite definite. We may conceive these two motions to be superimposed, and so obtain a series of flow diagrams of the type shown in Diagram 3. These are all possible forms of non-viscous flow, although the circulation could not be created by the motion of the wing without the action of viscosity. The exact form of flow depends upon the relative strengths of the linear and the cyclic motions.

It seems that a good approximation to the lift of a wing might be obtained by a calculation by non-viscous theory if we could determine what governs the strength of the circulation which is produced through viscosity; and in relation to scale effect the question of interest is whether this depends upon the magnitude of the viscosity or only upon the existence of viscosity. In the latter case we have a reason for expecting no scale effect upon lift.

It will be observed that the flow pattern of Diagram 1 presents difficulties when regarded as a possible form of flow in a real gas. Firstly, at the edges the velocity is theoretically infinite, which violates the assumption of constant density as air must expand greatly at this point; secondly streamlines very close to the wing double back twice upon themselves and viscosity would bring large couples into play to resist this. This form of flow would at once break down by the formation of eddies, and Joukowski has endeavoured to calculate lift on the assumption that the circulation set up is just sufficient to avoid this form of flow by bringing the "stagnation point" to the sharp edge. Difficulties arise because the circulation which secures this condition at the trailing edge is not in general the same as that which is required to secure it at the leading edge and the method also breaks down if neither leading nor trailing edge is at all sharp. These troubles were avoided by Joukowski by experimenting with aerofoil sections with well-rounded leading edges and sharp trailing edges. The illustration showing some results of his work indicates, I think, that his method gave

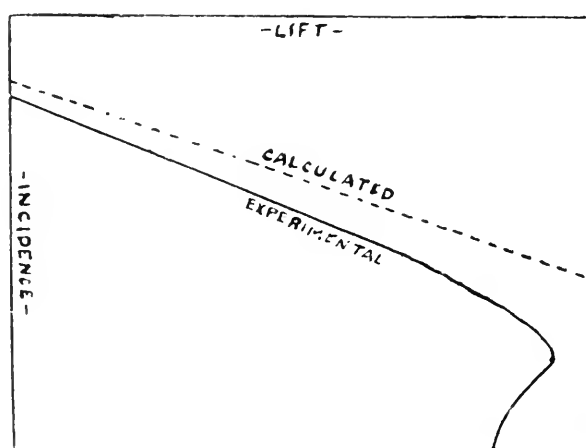


FIG. 3.

Comparison of Joukowski's calculations of lift with measured values.

a remarkably good approximation to the facts. It does not, of course, provide any explanation of the breakdown of lift at the critical angle. It is not improbable that the actual flow is to some extent periodic, and it is, I think, certain that the streamlines do not completely come together at the trailing edge; under the wing the stream probably leaves the aerofoil at the trailing edge, while above it leaves at a point, near the trailing edge of fine angles of incidence, moving forward slowly at first and rapidly as the critical angle is approached. There is always a small turbulent wake enclosed between the convergent streams, which

becomes large when the wing stalls. The circulation and the lift would therefore be less than this method estimates. The interest of this theory in relation to our subject lies in the implication that the mechanism of lift depends principally upon the existence of viscosity and little upon its magnitude, leading us to expect little scale effect upon lift. We should expect larger scale effect where the edges of the aerofoil were well rounded.

Prandtl and some others working with him have also applied the theory of non-viscous fluids to aeronautics, but their work rests upon a less conjectural basis. We have so far considered only two-dimensional flow, to which we can only approximate in practice by the use of aerofoils of high aspect ratio. Starting from the two-dimensional viscous flow round a wing of given section and of infinite aspect ratio, Prandtl has deduced valuable theorems about the three-dimensional flow round a wing of finite aspect ratio, so that from a test of a wing of any one aspect ratio the characteristics of wings of the same section and of other aspect ratios may be calculated. Other theorems deal with multi-plane systems, with the influence of the proximity of the ground and of the walls of a wind channel.

The layer of fluid in contact with a body is at rest relative to the body, and the velocity gradient close to the body is steep in comparison with gradients elsewhere in the fluid. Measurements of velocity in air flowing along a surface show the very small distance at which there is a sensible reduction of velocity in comparison with the length of surface traversed. The tangential stresses in the fluid due to viscosity are therefore relatively great close to the surface of the body, and while viscosity may be responsible for the lift by producing a circulation, the flow at a little distance from the wing may be calculable by arguments which ignore the viscosity if they include the circulation to which it gives rise. We may summarise the argument by saying that the action of viscosity is concentrated towards the surface of the body. This constitutes the justification of Prandtl's application of non-viscous hydrodynamics to aeronautics. Another well-known application of non-viscous hydrodynamics is the theorem of Froude relating to screw propulsion, which has been subsequently combined with the Aerofoil Theory of Airscrews, most successfully, I think, by H. Glauert's recent development of Prandtl's work

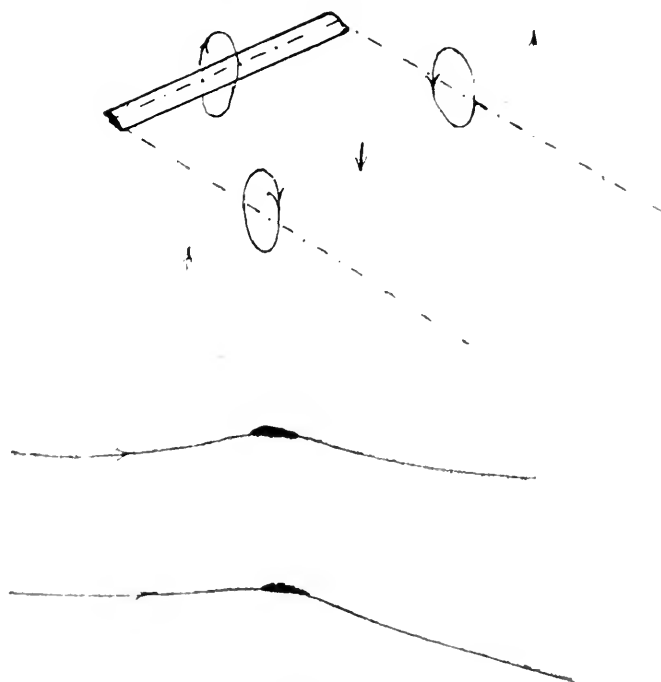


FIG. 4.

I can only give here a brief outline of Prandtl's work. Consider a finite wing experiencing a uniform lift along its span. There will be a uniform circula-

tion along the span which cannot cease at the tip, as by a theorem of hydrodynamics vortices cannot have a free end. A vortex must therefore trail from each tip. (In practice the lift will not be uniform to the tips, and the wing will therefore trail a sheet of vortices, the strength of the vortices from each portion corresponding to the fall of lift.) Comparing the finite wing with a hypothetical wing of infinite span, it will be seen that the trailing vortex system gives a downwash trend to the stream within the span and an upward trend beyond the tips. Whereas the flow before and behind the infinite wing is symmetrical (on the basis of non-viscous flow with circulation), the downwash behind the finite wing is greater than the upwash ahead, and the air at the wing has a downward trend. The wing moves in a downwash of its own producing.

This downwash at the wing can be easily calculated with sufficient accuracy. The method of estimating the lift and drag of the finite wing from those of the infinite wing is shown by the table in which ϵ represents the downwash at the wing:—

Aspect ratio.				Infinite.	Finite.
Lift coefficient	...	...	...	k_L	k_L
Incidence	...	...	...	α	$\alpha + \epsilon$
Drag coefficient	...	...	...	k_D	$k_D + \epsilon k_L$

This shows the incidence at which the two wings give the same lift and the drag coefficients which then obtain.

Infinite aspect ratio is the datum of the theory, but, of course, in practice the datum will be a test upon a wing of some finite aspect ratio.

Prandtl calls this increment of the drag at given lift by the trailing vortex system the "induced drag," and the drag of the wing of infinite aspect ratio and of the same section he calls the "profile drag." If there is no scale effect on lift, we may expect scale effect on drag to be confined to the "profile drag," and the variation to be greater in proportion to the whole drag at the smaller angles of incidence.

These circulation theorems have received considerable experimental verification. They are found to give with good accuracy the effects of change of aspect ratio and the direction of flow at points not too close to the wing. Unfortunately, the most useful calculation of direction of flow, the downwash at the usual position for the tailplane, is complicated by the rolling up of the vortex sheet, and has not so far been accurately made.

In so far as reliance might be placed upon this form of calculation, it is clear that a solution obtained by a model experiment should be independent of scale, and a class of problems exist in which wind channel results apply without doubt to the full scale. As an illustration there should be no scale effect upon the relation between lift and downwash, whatever scale effect may exist between lift, drag and incidence.

To summarise the conclusions of the theoretical discussion:—

- (1) There is a law of dynamic similarity to which we do not conform in our model experiments.
- (2) Until the mathematical theory of the flow of a viscous fluid is further advanced we cannot arrive at a precise or certain theory of scale effect when this law is violated.
- (3) Our experience leads us to believe that by experimenting with models to the larger scales which we use we obtain a good approximation to the full scale conditions.
- (4) We have some reason to believe that scale effect upon lift will be less than upon drag (until the stalling angle is approached).
- (5) Certain applications of non-viscous theory to aeronautics are justifiable, and these are independent of scale.

Conditions of Model Tests.

In practice the conditions under which model work is conducted differ from those of full scale flight, and the co-relation of model and full scale involves the co-relation of these conditions.

Model experiments may take various forms. We may test a model of a complete craft in free flight or we may make measurements upon the whole or upon parts of a model aircraft in a constrained motion. In the former case, generally employed for investigating or demonstrating stability of flight, we must conform to certain conditions, which do not concern us in the latter case. The density of the model must be the same in proportion to the density of the air, the mass must be similarly distributed, and the action of gravity introduces the condition that v^2/lg must be the same. These conditions are easily obtained.

Experiments in constrained motion are employed for measurement of air forces, and I am confining my attention to this, the larger side of model work. In the case of rectilinear motion at constant speed the forces depend upon the relative motion, and it is convenient for a variety of reasons to hold the model fixed and cause the air to move past it. The apparatus employed is the wind channel or tunnel, of which two distinct types are in use. In one, the stream of air is an open jet, but in those used in this country the stream is bounded by four flat walls. To represent rotation the model must be rotated, and no difficulty arises in representing an airscrew rotating or a wing banking. The yawing and pitching motions do, however, present difficulties, as they involve in a wind channel change of the yaw or incidence, which they do not necessarily involve in flight. Producing the rotation without change of attitude requires a curved flight path, and the model must be moved through the air to secure strictly the correct conditions; but it is usual to obtain the forces required by causing the model to execute a small oscillation in the wind channel, assuming that the damping of the oscillation is entirely due to the angular velocity. I have, however, only space here to discuss the case of straight uniform motion.

The wind channel is designed to produce a steady parallel flow of uniform velocity, and the variations of speed observed in a good channel are of the order of 1 per cent. There is a very small drop of pressure as we pass downstream, for which allowance is made when necessary, as in testing airship models. The air is drawn in through a honeycomb to avoid large eddies, but it must be full of small eddies, and it is possible that this micro-turbulence may have some influence upon the experiments, although I do not believe that it introduces serious errors.

The method adopted for the support of the model in the channel is of great importance. The introduction of clumsy parts into the channel is a fruitful source of trouble. The balances are situate outside the stream, and in the best practice the model is suspended from them as far as possible by fine wires. Even these offer a considerable resistance and must be reduced to a minimum. Correction is easily made for that part of the drag of supports which acts directly upon the model; but it is also important to ensure that the supports do not cause a serious deflection of the flow.

The walls of the channel exercise a constraint upon the flow, and influence the results to an extent which depends upon the relative size of the model and the magnitude of the air forces. The Froude propulsion theorems have been extended to provide a theory for correcting tests of airscrews in a channel, and the work of Prandtl provides a theory for correcting tests of wings. The latter deserves some discussion here.

If the walls of the channel were optical mirrors, series of images of the model would be seen. The model in the channel is more or less aerodynamically equivalent to a model flying in formation with these images. By the circulation

aerofoil theory the influence of these images on the model may be calculated. The corrections are :—

$$\Delta\alpha = 16 Sk_L/h^2$$

$$\Delta k_D = 0.27 Sk_L^2/h^2$$

where S is lifting area of model and h the breadth of a square channel.

The following table shows the percentage correction applicable to the lift/drag ratio of biplane wings 6in. \times 36in. of R.A.F. 15 section, tested in a 7ft. wide channel and in a 4ft. channel.

Lift coefficient	...	0.15	0.275	0.40	0.475
Seven-foot channel	...	4	7	9	7%
Four-foot channel	...	12	21	27	21%

Such a model would probably never be tested in a four-foot channel, and some doubt may be felt as to the reliability of a correction of such magnitude; but the correction for the seven-foot channel is large enough to receive attention, and I think that the theory may be relied upon for corrections of this size, as it has been found to bring tests of a 6in. \times 36in. monoplane in four and seven-foot channels into good agreement.

The interference of the channel walls increases the rate of change of lift with incidence and reduces the stalling angle; reduces the drag by an amount proportional to the lift, giving the drag curve a less steep slope; it also reduces the downwash and so increases the stability and makes the model relatively "nose-heavy."

An inventor recently claimed to have designed a wing which gave very high lift/drag ratio at high lift coefficients, quoting wind channel results in support. I found that his claim was incredible on the basis of the Prandtl circulation theory, but upon ascertaining the dimensions of the model and channel and applying the appropriate correction, the results became more normal. I have dwelt at some length upon this point because of its importance to all who use wind channels, and because the method of correction of results is a recent innovation in this country.

We have also to recognise that the model tests which we make are generally tests upon isolated components which must be applied to complete aircraft with caution. The completest model tests which we are accustomed to use do not represent the aircraft flying under its own power. The action of the airscrew slipstream upon the tail unit is important and highly complex, and I should hesitate to estimate it. The mutual interference of parts is often large, especially when the parts are of low resistance form.

Full Scale Conditions.

The full scale conditions do not call for the same discussion as the model. They are the actual conditions in which we are interested and of which the model conditions are representations. In neither case am I entering into discussion of the accuracy of measuring apparatus. The full scale aeroplane may be employed as a laboratory for analytical observation; the conditions are essentially correct although the analytical method may err, as for example, if the full scale aeroplane be regarded as a means of obtaining the characteristics of a wing isolated in free air. One important point calls for notice. We wish to know the performance of the aeroplane in still air, and errors are introduced by the unknown vertical currents in the atmosphere. A small current introduces a considerable error. The quantities by which the performances of an aeroplane are usually expressed—rate of climb, speed in level flight and gliding angle—are affected by vertical currents, the rate of climb or descent being measured relative to the ground. The quantity which should be measured in order to eliminate the effect of vertical currents is the inclination to the horizontal of the direction of motion of the craft through the air.

We hope by the development of certain apparatus to be able to do this, but at present we rely upon taking a multitude of observations spread over a period, assuming that the average vertical flow is zero. With present methods I do not regard full scale results as reliable to any good degree of accuracy, unless they are based upon a large number of observations.

Experimental Investigation of Scale Effect.

The use of models requires to be based upon an extensive experimental foundation. Until this is achieved it cannot be regarded as better than the best available form of guesswork in the present state of our theoretical knowledge. This experimental foundation has been indirectly built up by the use of models in the development of aeronautical design; but a direct attack by careful systematic experiment has led to more accurate knowledge. The Royal Aircraft Establishment has been engaged for some years upon full scale experiments for this purpose. In the earlier stages the characteristics of various wings were deduced from observations of performance of aeroplanes together with calibrations of the engines and airscrews and model tests of the interaction of airscrew and fuselage and of the drag of struts, wires, undercarriage, etc. More recently the full scale work has been simplified by the elimination of the power unit, thus avoiding a possible source of error and reducing the full scale test to one which can be closely repeated upon the model. The measurements comprise the incidence of the wings and the lift and drag of the complete aeroplane with the airscrew locked in a definite position. The airscrew is stopped in these experiments as the simplest means of reproducing the correct revolutions on the model. The model tested for comparison is as far as possible an exact replica of the aeroplane, the chief difference being the omission of the bracing wires on the model. It is known that there must be a scale effect upon the struts of the model owing to their very small size, but this scale effect is found roughly to compensate for the omission of streamline wires. The fins of air-cooled engine cylinders are not generally reproduced on the model, but care is taken to secure as far as possible the correct air passages round the engine, as this is found to influence the drag considerably. Radiators are reproduced by wire gauze offering the same resistance. Attention to such details in model work is quite important. The elevators of the model are set at the angles which are found to give equilibrium of the air forces on the model about the point corresponding to the centre of gravity of the aeroplane.

In the full scale experiment the quantities measured are the weight of the aeroplane, the indicated air speed, the air density (by pressure and temperature) the rate of loss of height, and the inclination of the aeroplane to the horizon.

The experiment aims at determining the accuracy with which the lift and drag of a complete aeroplane when gliding are predicted by a careful experiment upon a complete model, and from the result we may infer that accuracy with which its performance under its own power would be given by a corresponding model test.

Another line of investigation is by the measurement of the pressure at a large number of points over the wing in flight and in the wind channel. Vertical currents in the air still constitute a source of trouble as the incidence is derived from the speed, rate of change of height and inclination of the aeroplane to the horizon. These measurements enable us to compare lift and centre of pressure, but only the contribution of the normal pressures to the drag.

By flying an aeroplane with the centre of gravity in different positions and altering the tail plane angle, the characteristics of the tail may be deduced from observations of elevator angles and the force on the control column. From this it is possible to proceed to determine the centre of pressure on the wings. Centre of pressure has also been obtained upon an aeroplane with a hinge in the fuselage

by direct measurement of the moment of the forces on the tail about this hinge, and this work has been accompanied by comparative model tests.

Experimental Evidence.

Space does not permit me to review the experimental evidence at all extensively, and I shall only quote some typical results subsequent to the evidence dealt with by the Scale Effect Sub-Committee in 1917. I had hoped when I undertook this Paper to have had available the results of pressure plotting experiments upon a B.E.2c and of gliding experiments upon the Bristol Fighter and three modifications of that aeroplane; but unfortunately the work has advanced more slowly than was expected.

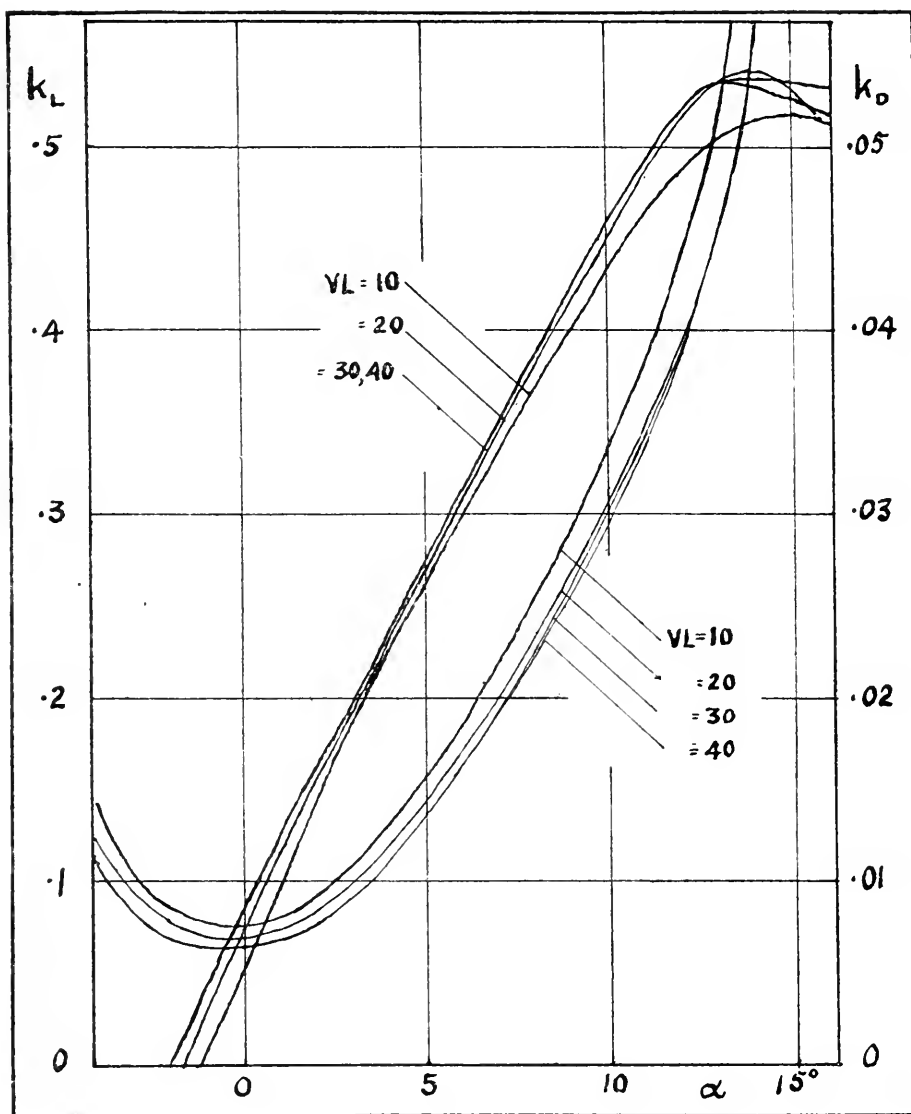


FIG. 5.

Typical scale effect on a thin section aerofoil in the wind channel.

The first set of curves show results of wind channel tests of an aerofoil of aspect ratio 6 at values of VL of 10, 20, 30, 40, L being the chord of the wing. The tests at 20, 30 and 40 were made at one time in one channel upon the same model, but the 10 test was made upon a smaller model in a smaller channel. The scale effect over the whole range is not inconsiderable, but it is becoming small at the upper end. The scale effect is more clearly and strikingly exhibited by the second set of curves which are cross plots at 0° , 5° , 10° incidence and show the ratios of the coefficients of lift and drag to the values at $VL = 30$. It was customary

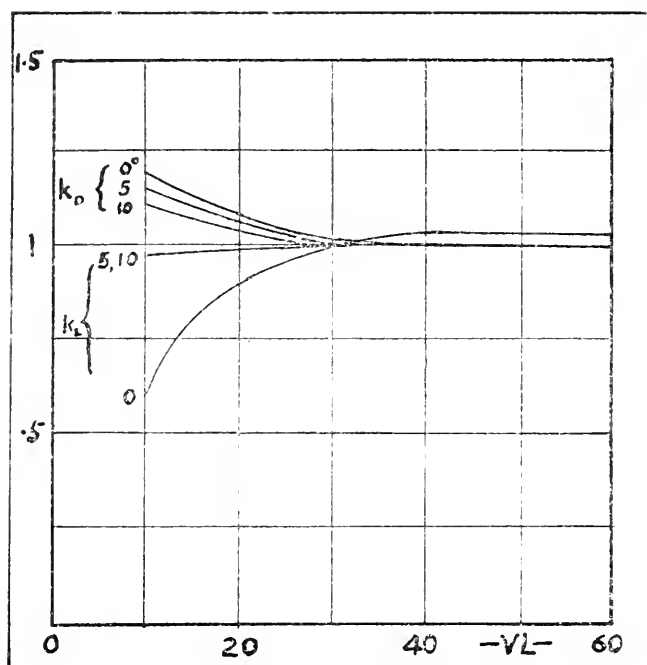


FIG. 6.

Typical scale effect on a thin section in the wind channel.

to test wing sections at $VL = 10$ and these curves show at once that this was not satisfactory; but that the modern practice of tests at $VL = 30$ or upwards, made possible by the use of seven-foot channels, gives results which may be hoped to approximate well to the full scale, a conclusion indicated by the curve for the drag of strut section which I quoted above.

It may be noted that, with the exception of the lift at fine angles, the scale effect upon lift is considerably less than that upon drag.

The results of comparative gliding experiments, full scale and model, which I quote, were obtained upon a B.E.2E aeroplane. The curves are the wind channel measurements of the lift and drag of the complete model corrected for the limitations of the stream. The points are the results of glides and give the lift and drag of the complete aeroplane. These results have been published in R. and M. 762, but were presented there in a different form, and the full scale lifts above 16° incidence have been taken from some unpublished experiments upon the stalling speed. It was previously believed that the full scale maximum lift was in the neighbourhood of 0.6, but the technique of this experiment has been developed recently and both the experiment from which these results are quoted and other experiments upon Bristol Fighters show now a good agreement between the maximum lift full scale and model.

At first inspection the agreement of the model and the full scale is very satisfactory indeed, but further consideration shows that a definite scale effect is indicated. The model differs from the full scale aeroplane by the omission of all bracing wires, and these are estimated to account for a drag coefficient of 0.0044 on the full scale. We know, however, that there must be a large scale effect upon the struts, which are very small members. These are estimated to contribute 0.001 to the drag coefficient, and will contribute three or four times as much on the model, leaving, however, a small balance to be explained by some scale effect upon the larger components.

For the sake of including results obtained with a more modern and efficient aeroplane, with wings of the later and commoner section R.A.F. 15, I also reproduce measurements obtained upon the S.E.5A gliding (R. and M. 603), together with comparative model figures one-eighth scale at 80 f.p.s. (R. and

M. 739). The comparison is upon the same basis as before, but the airscrew was stopped in different positions in flight, whereas the model airscrew was fixed with blades vertical. No measurement of incidence was made in flight, and the drag coefficient is therefore plotted against the lift coefficient. The agreement is very satisfactory considering the somewhat less accurate nature of this experiment. In this case the wires contribute about 0.002 to the drag coefficient.

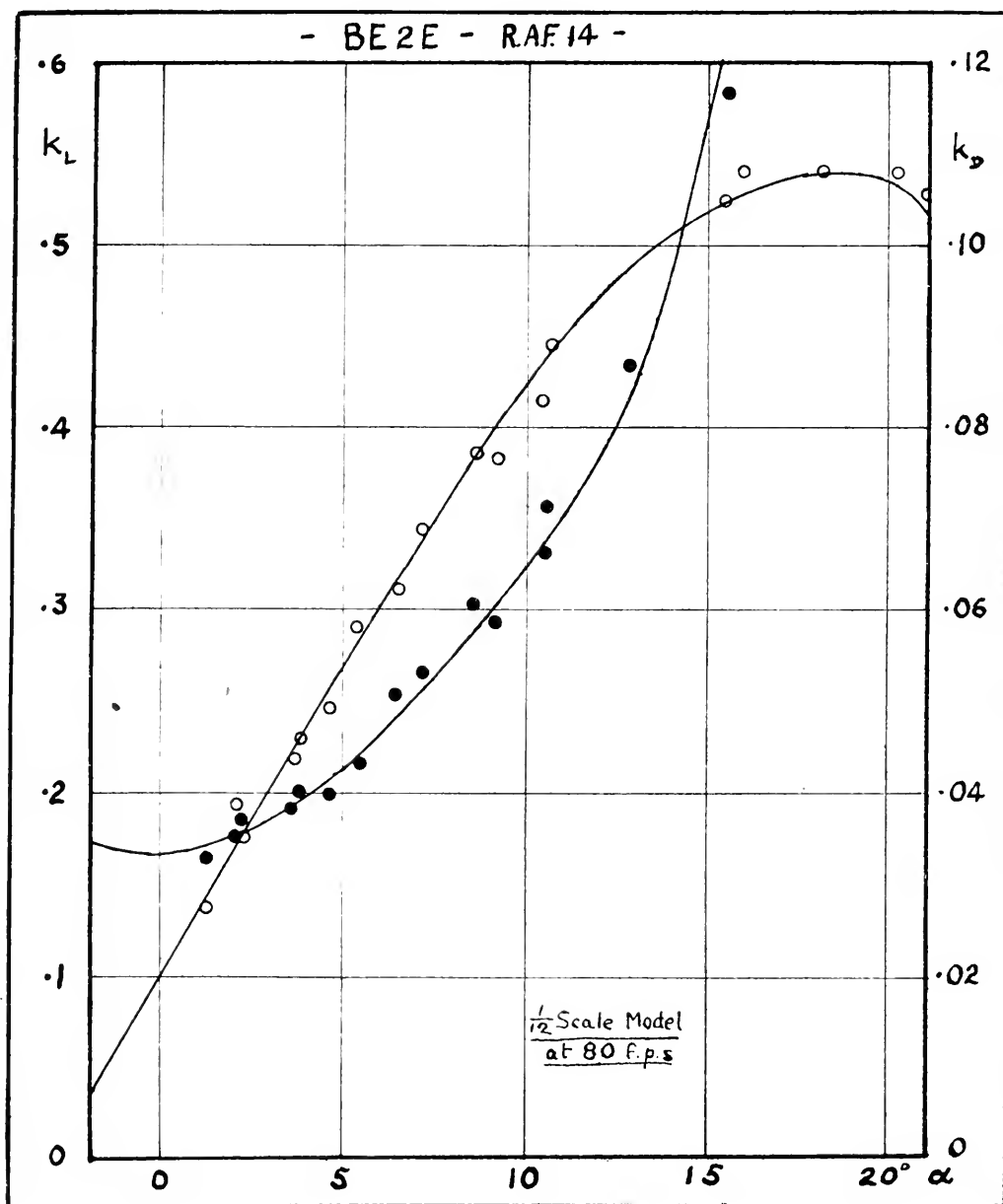


FIG. 7.

Comparison of full scale and wind channel values for the lift and drag of a complete aeroplane. The points were obtained by glides (full scale) and the curves from a test of $1/12$ scale model at 80 f.p.s.

The drag of a full scale wing is somewhat less than that of a model tested at $VL = 30$ to 40 , and this discrepancy is greatest at the minimum drag (*i.e.*, at fine angles). The reports which the Aeronautical Research Committee have published have indicated that the drag curve has a steeper slope full scale than model. This can be partly, but not entirely, explained by the omission of the correction for the limitation of the stream in the wind channel, which had not been applied in any of that work.

These results are typical of others from which, in my opinion, we may conclude that carefully conducted wind channel tests at sufficiently large values of VL give a very good prediction of full scale performance for the most common type of aeroplane, the thin wing biplane; but we must be cautious of generalising this conclusion.

A highly cambered section, known as R.A.F. 19, has been the subject of extensive experiments. At $VL = 10$ this section gives a remarkably high maximum lift accompanied by a sudden stall with a duality of values of lift over a small range of incidence at the stall, the higher or the lower value occurring according as this region is approached by increasing or decreasing the incidence. At higher values of VL the stall becomes more normal. The full curves show

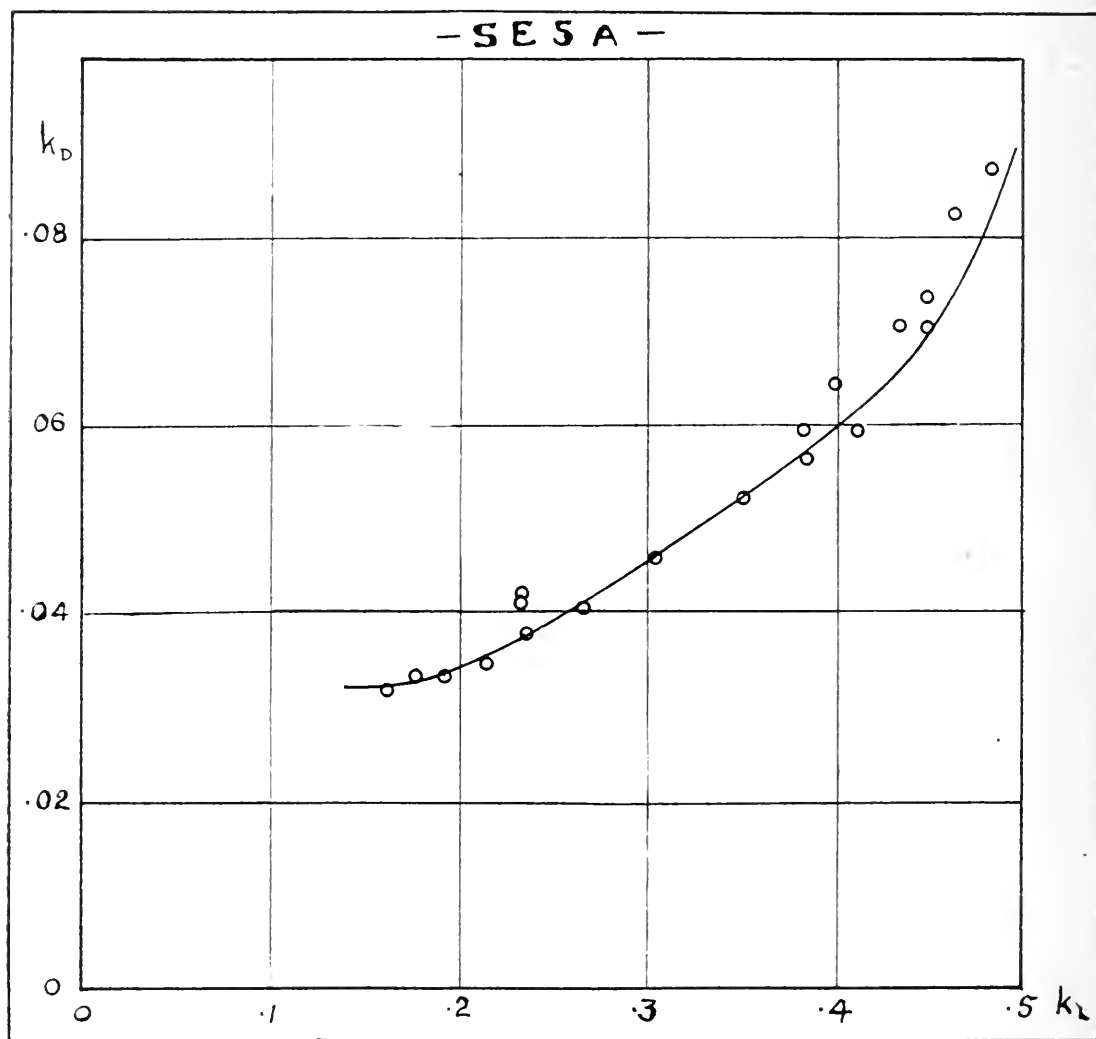


FIG. 8.

Comparison of full scale and wind channel values for the lift and drag of a complete aeroplane. The points were obtained by glides (full scale) and the curves from a test of $\frac{1}{8}$ scale model at 80 f.p.s.

the results of model tests at 50, 80 and 120 f.p.s. upon a model B.E.2E with wings of this section. The curves at 80 f.p.s. seem to be reaching some finality of form, but the broken curves giving the results of full scale experiments exhibit a very wide departure from the model in the case of lift. The slope of the full scale lift curve is less steep, and the maximum lift coefficient is only 0.7 as against 0.9 of the model. An endeavour was made to extend the range of the model tests by means of an aerofoil 1.1 feet by 4.4 feet in the fastest channel we have in this country (R.A.E. No. 2 7ft.) and a steady decrease in maximum

lift was obtained. This further test was suggested to me by information I acquired on a visit to Germany. I found that the Göttingen laboratory had made tests up to very high values of VL and had found that the maximum lift of thin or moderately cambered aerofoils increased with VL or became stationary; but that very highly cambered aerofoils exhibited the property we observed on R.A.F. 19. The curves exhibit the variation of the maximum lift of such aerofoils with

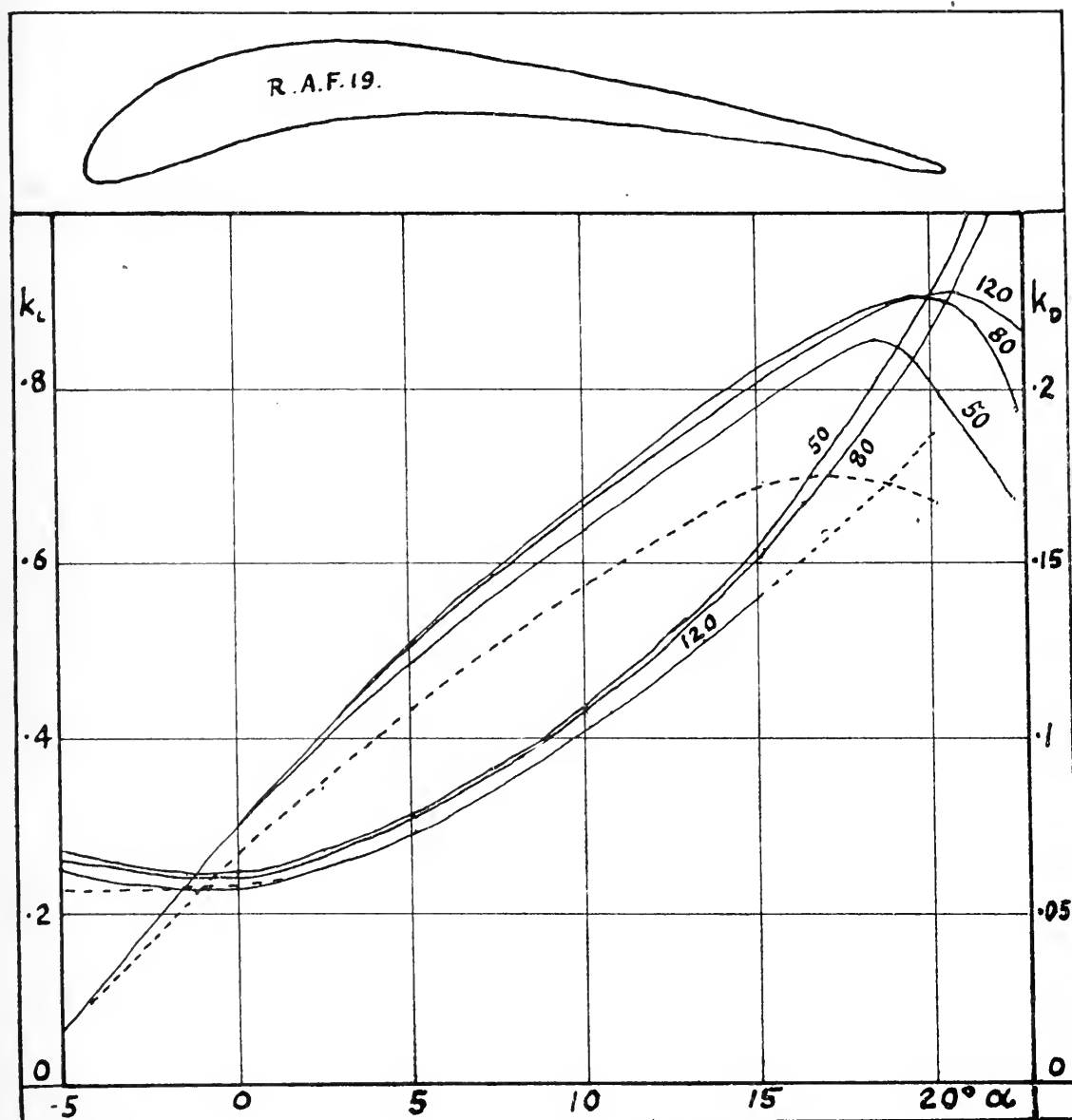


FIG. 9.

Comparison of full scale and model values for the lift and drag of a complete aeroplane. The figures on the curve indicate the speeds in ft. per sec. at which the $1/12$ scale model was tested. The dotted curves give the results of glides (full scale).

VL , occurring of course at different angles; the increase of R.A.F. 19 at low values of VL and the decrease of the special high VL test, the B.E.2E model and the full scale, and a Göttingen test upon an aerofoil whose upper surface closely resembled that of R.A.F. 19, although the section is considerably thicker. This unfortunate phenomenon is well established. It seems to be a property of large curvature of the upper surface. The conclusion that slotted wings will behave in a similar manner must not be drawn. Moderately thick wings, such

as section 64, do not exhibit this scale effect, and thicker wings than 64 may attain the lift given by the model.

Fortunately R.A.F. 19, on account of its very high drag, is of no value for biplane construction; but the need for research upon the scale effect on the wings of internally braced monoplanes, in which very thick sections occur, is clearly indicated.

Discussion of the question of scale effect upon the centre of pressure on a wing presents difficulties. From the evidence I have quoted, little scale effect above $VL = 30$ would be expected for thin or moderately thick wings. There is little scale effect on the model above this value and it is difficult to reconcile scale effect upon centre of pressure with absence of scale effect on lift. The

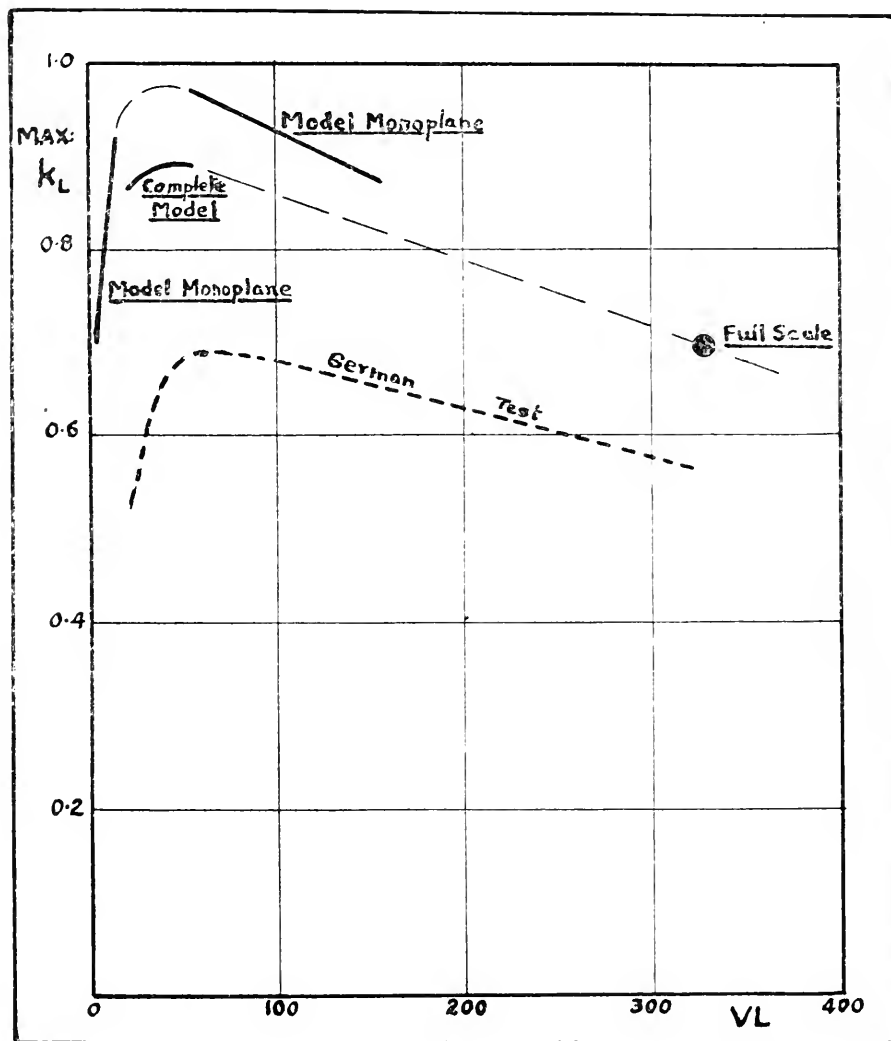


FIG. 10.

Showing the variation of the maximum lift of highly cambered wings with VL .

principal experimental evidence is that obtained by the broken body experiment and this has always given the full scale centre of pressure ahead of the model by from 2 to 5 per cent. of the chord, an amount which has quite a sensible effect upon tail setting and stability. We have been unable to find any reason for error in the experiments, and are seeking information by other means. The comparative pressure plotting experiments upon which we are still engaged should assist in clearing up this question.

Conclusion.

I have endeavoured in this Paper to give a survey of the subject at the risk of some loss of lucidity in the attempt to cover a wide field. Two factors in the

relation between wind channel tests and the full scale seemed to require discussion; the differences between the conditions of the wind channel and those of free flight and the possible results of the failure to conform to the Law of Dynamic Similarity. I have dealt at some length with theories which I think help towards an understanding of the use of model tests, and this has prevented me from examining the experimental evidence at all extensively. Ultimately, we may achieve a complete theory of viscous flow; but this is far off and at present theory does not take us far. In the meantime we must be prepared to find departures of the full scale from predictions based upon the model; but as the experimental evidence has accumulated, the use of model tests has acquired a basis of considerable certainty. Scale effect is seen to be evanescent upon most of the forms which we wish to use, and it is practicable to conduct the model tests upon a scale sufficient to give accurate predictions. On the other hand, we wish at times to use forms, typified by R.A.F. 19 wing, of which this cannot be said, and I am anxious to see a compressed air wind channel built as the most rapid means of advancing the investigation of these shapes; but in any case the comparative full scale and model work should be vigorously continued by the most accurate means we can devise.

Although the relation between model and full scale is not fully understood and the wind channel is not infallible, it is, I think, generally agreed that it has a wide sphere of usefulness, is a method of good reliability, and valuable both as an aid to design and as a means of rapid experimental investigation.

APPENDIX.

Model and Full Scale Airscrews.

Measurements upon model airscrews are useful for testing aerodynamic theories of screw propulsion and for investigating the effects of airscrew on aeroplane and vice-versa. For predicting the performance of the full scale screw a model test is of doubtful value unless the model is elastically as well as geometrically similar and tested at the full scale speed. This requires a channel capable of flying speeds and a motor of considerable power for driving the airscrew. Two additional factors enter into the airscrew problem:—

- (1) Twisting of the blades under air forces and centrifugal action.
- (2) Compressibility of the air.

The air forces will be the same at the same speed if the airscrews are similar and the ratio of the elasticity of the air to its density is the same. This ratio is equal to the square of the velocity of propagation of pressure waves (a) and the new condition of dynamic similarity introduced is that v/a must be the same. This condition is certainly unimportant up to $v/a = \frac{1}{2}$, but probably becomes important when v/a exceeds $\frac{3}{4}$. The speed of sound (a) is proportional to the square root of the absolute temperature and so does not vary greatly under practical conditions. The stresses due to the air forces therefore vary approximately as ρv^2 and the centrifugal stresses vary as σv^2 , σ being the density of the airscrew material. If the material has the same density and elasticity the distortion of the blades is therefore similar at the same speeds.

DISCUSSION.

Mr. A. KIRDANY, dealing with the first part of the paper, said the author had shown a slide with three figures. He would like to know how the middle one was obtained—the one showing the cyclic motion. Was it a mathematical calculation? With regard to Joukowski's method of getting the proper strength of the circulation to move the stagnation point right to the trailing edge, was that possible in any degree with any angle of incidence, and was there a relation between the angle of incidence and the strength of that circulation?

Colonel DE VILLAMIL said he was a firm believer in the principle of similitude and that consequently he did not agree with the lecturer on some points. He believed that the real reason why there was a difference observed between full scale and small scale experiments was that they were dealing with different forms of motion. In full scale work they were dealing with uniform motion, but in model work they were dealing with *accelerative motion*. If there were no acceleration they would find that dimensional effect disappeared, and they would find that the resistances were equal; he believed they would find that the full scale results agreed absolutely with those of the model.

The principle of relativity is only applicable to the *differential equations* of the second order— d^2x/dt^2 , say—and not to the *finite equations*, which are those actually observed and measured. When you integrate, in order to get the finite equations, you have to add constants of integration; and relativity does not necessarily hold good for these equations.

Mr. E. RELF said they were all grateful to Mr. Wood for his lecture; he had given them a very coherent account of the relation between model and full scale work at the present time. Dealing with work which was being done at the National Physical Laboratory and which should shed light on the subjects dealt with in the paper, he said that they were investigating the fluid flow round an aerofoil in a wind tunnel, and that the Chairman, Professor Bairstow, was making calculations of the flow round the same aerofoil in a non-viscous fluid. A comparison of the results in the two cases would show where the viscous and non-viscous flows chiefly differed and should be a great help towards understanding the theory of viscous flow. Also they would be able to check the circulation theory and the experiments should give a direct confirmation, or otherwise, of the Prandtl theory. With regard to another point raised by Mr. Wood, namely, the influence of the propeller when comparing the model and the full scale experiments, that was an extremely difficult subject and probably the most complicated that they had to deal with, but that also would be investigated very shortly. They had a model almost ready to go into their large wind channel containing an electric motor of special design, and so they would be able to add horizontal flight and climbing tests to the comparisons seen that evening, and thereby greatly increase their knowledge of the co-relation between model and full scale work.

Mr. H. F. PARKER asked whether there was any reason why a greater value of ρ/μ might not be obtained by using a gas other than air in a closed tunnel. For instance, CO_2 might be used; this gas had a value for ρ/μ of nearly twice that of air. It was easily obtainable and should not be difficult to work with. Another possible gas was chlorine, which had a value three times that of air. This would be objectionable to handle, but if the tunnel was properly sealed and reasonable precautions taken useful results might be obtained. There were other heavy gases that might be used in this connection. Two cases might be considered; first, that in which a gas having a value for ρ/μ greater than air was used at atmospheric pressure to partially bridge the gap between present model and full scale results; and second, the possibility of getting full scale values from models by compressing such a gas. In the latter case a special tunnel would have to be constructed to resist considerable pressures. These pressures would be much less than those necessary to secure similar results in a compressed air tunnel and the question that arose was whether the simplification in construction compensated for the difficulties of working with undesirable substances. In the case of the tunnel at atmospheric pressure, however, it might be possible to secure results of considerable value for comparatively little trouble. A closed circuit tunnel would be necessary—there was one of that type, eight feet in diameter, at the Washington Navy Yard, but he was not familiar with the detail construction of the large tunnels in this country, though he believed most of them to be of the open end type. However, such a tunnel could be made entirely gas tight

with little difficulty, and as the observers would be outside working in pure air they would run little risk. The troublesome operations would be those of filling the tunnel and of setting the model in position. Provided precautions were taken to remove or protect anything likely to be attacked, chlorine might actually be safer than CO_2 as observers could smell any leak long before there was enough of the gas in the air to harm them. The absence of a warning of this nature might make CO_2 more dangerous.

The CHAIRMAN said he remembered, not very many years ago, that there was much disagreement between measurements of model and full scale experiments. One of the points always to be remembered when comparing model and full scale experiments was the degree of accuracy of the experiments. So far they seemed to have removed a great deal of the error of observation, and he, with Mr. Wood, would like to see a great deal more attention paid to the co-relation of model and full scale work. But it was when Mr. Wood tried to interpret scale effect in terms of fluid motion that he (the Chairman) found himself unable to follow him; the existence of the circulation theory was a perpetual trouble of his. Dealing with the work being carried out by himself and others with regard to the application of Prandtl's theory of non-viscous fluids to aeronautics, there was little doubt that they would get a solution to compare with experiments, but he did not expect to find the circulation at all in the experiments. It seemed to him that viscous fluid motion had not got circulation in it. It was difficult to know why the circulation theory accounted for so much as it did. In a paragraph in the paper, Mr. Wood had said, "On the assumption that the flow is steady laminar flow the velocity gradient and the drag exerted on the surface can be calculated." By "laminar flow" he (Mr. Wood) meant the conventional flow, *i.e.*, the flow parallel to the plate itself. But later, at the end of the paragraph, the author seemed to have identified laminar flow with steady flow, because he said, "The state of steady flow occurs, however, only at very low values of $vl\rho/\mu$, and the values with which we are concerned in aeronautics are well inside the range of turbulent flow." He (the Chairman) did not think there was any connection between laminar flow and steady flow, and he did not think it was a well-founded statement, that the values with which they were concerned in aeronautics were well inside the range of turbulent flow. His own impression was that until they passed the stalling angle of a wing the flow was steady. He did not say that it was any better established than the contrary hypothesis, but he thought they could hold the opinion on present evidence. If they took the case of a flat plate which was not infinite in length, then obviously they could not get laminar flow. Suppose the fluid flowing over a plate of finite width but infinite length. There was no friction on the plate until the particles actually came into contact with it, and then the intensity of the resistance suddenly became very big, so that there was a slowing up of the streamlines and a gradual widening. Certain calculations of flat plates where $vl\rho/\mu$ was as great as 10,000 had just been completed, in which the flow was still steady, and his own impression was that for skin friction on a thin flat plate values of $vl\rho/\mu$ as high as we could reach were still consistent with steady motion. The whole subject was one of great difficulty, but one in connection with which we were beginning to see some light; whether or not the Prandtl theory could be accepted at the moment as anything more than empirical formulæ did not eliminate its value in aeronautics. He anticipated that it would be put on some better fundamental basis before many years were passed.

Mr. McKINNON WOOD, replying to the discussion, said he was not quite sure whether he was brave enough to reply to Mr. Kirdany, because he did not pretend to be a mathematician. Mr. Kirdany had asked how the circulation in the middle picture was calculated. Actually the figures were copied very freehand from a book. (Laughter.) He understood, however, from mathematicians that it was possible to calculate lines like that. In the calculation they did not know at the start for certain what sort of aerofoil they would end up with; but they ended with a shape, and if it were not the shape they wanted they tried again. It was possible to calculate forms of flow round bodies both in translation and in

circulation and to superimpose them, and by doing so in the right proportion they would get the stagnation point to come to the trailing edge at any angle of incidence. Colonel de Villamil, he gathered, had suggested that the scale effect that they observed from the wind channel to the full scale was due to the conditions of experiment being different. That was a point to which he (Mr. Wood) had referred and it was one they had always to bear in mind. The air in the wind channel was not the same as the air through which the aeroplane flew. Neither were absolutely uniform motions. In the air there might be a certain amount of turbulence, and probably a good deal more in the wind channel, and it had been found that, by introducing artificially a high degree of turbulence in front of fine shaped bodies in a wind channel it was possible to affect the drag quite considerably, but he did not know of any evidence that quite a large amount of turbulence in the channel affected seriously the lift and drag of an aeroplane wing. He was speaking throughout the paper rather from the point of view of aeroplane design than such things as airship resistance. He knew from experience that measurements of the drag of airships in different channels did not always give quite the same result. Another interesting thing he might mention was that at the R.A.E. they had measured the drag of a section such as the strut section which he had shown first. It was a blunter section than the one shown, a proposed section for an aeroplane streamline wire, and the scale effect on it was very large and very erratic. In trying to make measurements in different channels they had found they could not repeat them; the results were entirely different, so that where they had a flow which was critical—where they were in the region of large scale effect (if there was such a thing as scale effect)—then he believed turbulence in the air might make a great difference to the results obtained.

With regard to the use of CO_2 or chlorine or other gas in wind channels, Mr. Relf and he had both looked into that question, and had come to the conclusion that there was no real reason to prefer any other gas or liquid to air, which had obvious advantages from the point of view of convenience. The thing could be made to work with air, although considerable difficulties would be met.

At the last meeting of the Society he had heard the Chairman give his views on circulation and the Prandtl theory, and he (Mr. Wood) considered that it was very important to carry out the experimental work to which Mr. Relf had referred; it was only by carrying out experiments that they would find out whether or not there was circulation round the wing. He believed that sufficient measurements had been made of the flow round the wings of an aeroplane to indicate that the circulation which Prandtl supposed to be there was actually there. They had measured the direction of flow in front of and behind wings and off the tips, and except in the case of the measurements behind, where the calculations by Prandtl were not made to take into account the rolling up of the vortex sheet into two main vortices, the agreement between the measured values and those calculated by Prandtl were extremely close, and in the case of the measurements behind the wing the experimental value lay between two hypotheses.

He took it, when preparing the lecture, that there was very little hope held out in the chapter on scale effect in the Chairman's book on "Applied Aerodynamics." The law of dynamic similarity was stated, but there seemed to be nothing suggested which would justify them in using wind channel experiments and applying them to the full scale, and he had wondered why the Chairman should always have been so enthusiastic in insisting on the value of model work. He admitted that the whole of his theoretical arguments in the paper were extremely shaky; but he felt that there was a certain amount of reason in them, and he liked to see some glimmer of light on the subject suggesting that there was a theoretical justification for using wind channel results. On the question of steady and laminar flow, he thought when he wrote the paper that he was practically quoting from the Chairman's book. (Laughter.) He wrote it, perhaps, after reading the chapter rather late at night. Perhaps if he had said that the state of laminar flow occurred only at very low values, that might be a correct statement. He was talking about thin plates. He was thinking of the

state of flow in which they had resistance proportional to the speed and the state when they got the resistance more or less proportional to the square of the speed, which was the state they had in actual aeronautical problems.

At the conclusion of the meeting a very hearty vote of thanks was accorded Mr. McKinnon Wood for his interesting and lucid paper.

Professor B. MELVILLE JONES (*communicated*): I regret that I shall not be present to take part in the discussion of Mr. McKinnon Wood's interesting and comprehensive paper. I would like, however, to be allowed to lay emphasis on the great value to aeronautical progress of the work that has been done by Mr. McKinnon Wood and others at the R.A.E., in the direction of developing the technique of free flight experiments up to a point where sufficient accuracy can be attained to allow the results to be used as a direct check upon the value of model experiments.

It may be hard for anyone who has not tried it to realise the extreme difficulty of obtaining accurate results from experiments in free flight. I have had some experience of this type of work myself and I am convinced it will be found impossible to obtain any results whatever of the accuracy required in this connection without employing a staff who, besides being very capable experimenters, have had a wide and long experience of the peculiar difficulties to be overcome in this class of work.

In the absence of some all embracing theory whereby aeronautics could be freed from its present reliance on masses of experimental data—and there is no sign at present of such a theory appearing on the scientific horizon—there is nothing more certain than that real advances in aeronautics will depend to a large extent upon wind channel data. More or less exact quantitative data as to the air reaction on *separate* parts is an essential to progress, and if this cannot be obtained from theory on the one hand, or on the full scale on the other hand, there is no other source available than the wind channel or some equivalent small scale experiment. Full scale experiments are almost incredibly costly, when every source of expense is taken into account, so that—even apart from their extreme difficulty—they cannot be used to provide data of the immense variety that is required in aeronautical design.

The bulk of the empirical data required must, under these circumstances, be obtained on a small scale, but Mr. Wood has explained in his paper that we have no theoretical justification for supposing that the small scale data bears any relation whatever to the full scale. There is therefore only one course open to us and that is, whilst obtaining the bulk of our data on the small scale, to find out by a few well chosen full scale experiments those classes of data for which model experiments do represent the full scale, and in particular those classes in which they do not.

If the above statement of the position is correct it is obviously of vital importance to keep going the organisation whereby this full scale checking can be done, because without it we are building on sand, since at any time we may suddenly realise that the data on which we have been relying for some advance in design does not represent the facts. In the absence of some such organisation, whereby accurate full scale experiments can be made, we are in fact reduced to waiting for costly experiences of error in the prediction of the behaviour of new types to awake a suspicion in our minds that there is something wrong with our data. It takes, however, many such experiences to give us any feeling of certainty that there is an error and to indicate where the error lies.

The moral of all this is the absolute necessity of maintaining the experimental research staff at the R.A.E. and particularly that part that deals with full scale work, at the highest state of efficiency possible, having regard to the financial position of the country. My main object in making this contribution to the discussion is to emphasise this point at a time when severe financial difficulties make it important to distinguish clearly what branches of research are essential to progress on sound lines.

LIBRARY.

List of Current Periodicals.

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Advisory Committee for Aeronautics. Report	England ...	Irregular.
Aerial Age	America ...	Monthly.
Aero-club Argentine. Bulletin (El Avion)	Argentina ...	Monthly.
Aero-club de Espana. Boletin (Oficial)	Spain ...	Quarterly.
Aero-club de Portugal. Boletin (Revista Aeronautica)	Portugal ...	"
Aerodynamic Institute of Aachen. Abhandlungen	Germany ...	Irregular.
Aeronautical Abstracts	England ...	Monthly.
Aeronautical Research Committee. Reports and Memoranda	" ...	Irregular.
A.R.C. Internal Combustion Engine Sub-Committee Reports	" ...	"
L'Aeronautique	France ...	Monthly.
L'Aerophile	" ...	"
Aeroplane, The	England ...	Weekly.
Les Ailes	France ...	"
L'Air	" ...	Fortnightly.
Air League Bulletin	England ...	Monthly.
Aircraft	Australia ...	"
L'Ala d'Italia	Italy... ..	"
Automobile Engineer, The	England ...	"
Aviation	America ...	Fortnightly.
Bulletin de la Federation Aeronautique Internationale	France ...	Quarterly.
Canadian Patent Office Record	Canada ...	Weekly.
Cassier's Magazine. (See Engineering and Industrial Management.)		
Civil Aviation Communiques	England ...	Irregular.
Conquete de l'Air	Belgium ...	Weekly.
Coventry Engineering Society Journal	England ...	Monthly.
Deutsche Luftfahrer Zeitschrift	Germany ...	"
Engineer, The	England ...	Weekly.
Engineering	" ...	"
Engineering and Industrial Management. (Cassier's)	" ...	Fortnightly.
Ergebnisse der Arbeiten des Aeronautischen Observatorium	Germany ...	Irregular.
Export World and Commercial Intelligence. (Aeronautics)	England ...	Monthly.
Faraday House Journal	" ...	"
Flight	" ...	Weekly.
Flugsport	Germany ...	Fortnightly.
Gionalle dell'Avazione	Italy ...	Weekly.
L'Indicateur Aerien	France ...	Monthly.
Institute of Engineers and Shipbuilders of Scotland	Scotland ...	Irregular.
Letectvi	Cheko-Slovakia ...	Monthly.
Lot	Poland ...	"
Luftweg	Germany ...	"
Mechanical Engineering	America ...	"
Metal Industry	England ...	Weekly.
Meteorological Office. Professional Notes	" ...	Irregular.
Meteorological Society, The Royal. Official Journal	" ...	Quarterly.
Monthly Air Force List	" ...	Monthly.
Monthly Weather Bureau	America ...	"
National Advisory Committee for Aeronautics. Reports	" ...	Irregular.
North-East Coast Institute of Engineers and Shipbuilders	" ...	Annual.
Rassegna Marittima Aeronautica Illustrata	Italy ...	Monthly.
Rendiconto dell'Istituto Sperimentale Aeronautico	" ...	Alt. Months.
Revista Aeronautica	Portugal ...	Quarterly.
Revue de L'Aeronautique Militaire	France ...	Fortnightly.
Revista Mensile del Touring Club Italiano (Vie d'Italia)	Italy ...	Monthly.
Royal Engineers' Journal	England ...	"
Royal Institution. Proceedings	" ...	Annual.
Royal Meteorological Society's Journal. (See Meteorological.)		
Royal Society of Arts Journal	" ...	Fortnightly.
Royal Society of Edinburgh. Proceedings	Scotland ...	Annual.

TITLE.										COUNTRY.	CHARACTER.
Royal Society of New South Wales.	Transactions	...	...	...	...	...	...	...	...	Australia	Annual.
Sea, Land and Air	...	...	...	...	...	...	...	...	...	"	Monthly.
Society of Automotive Engineers	...	...	...	...	...	...	...	...	...	America	"
Steel Structures	...	...	...	...	...	...	...	...	...	England	Quarterly.
Svensk Motor-Tidning	...	...	...	...	...	...	...	...	...	Sweden	Fortnightly.
Technical Memoranda	...	...	...	...	...	...	...	...	...	England	Irregular.
Technical Notes	...	...	...	...	...	...	...	...	...	America	Monthly.
Technique Aeronautique	...	...	...	...	...	...	...	...	...	France	"
Technical Memos	...	...	...	...	...	...	...	...	...	England	Irregular.
United Service Institute of India	...	...	...	...	...	...	...	...	...	India	Quarterly.
United Service Magazine	...	...	...	...	...	...	...	...	...	England	Monthly.
United States Air Service	...	...	...	...	...	...	...	...	...	America	"
Vliegveld, Het	...	...	...	...	...	...	...	...	...	Holland	"
Wireless World	...	...	...	...	...	...	...	...	...	England	"
World's Carriers	...	...	...	...	...	...	...	...	...	"	"
Zeitschrift fur Flugtechnik	...	...	...	...	...	...	...	...	...	Germany	Fortnightly.



REVIEWS.

L'Aéronautique des Origines à 1922. Comte de la Vaulx, Paul Tissandier, Charles Dollfus.

It is a matter for increasing regret that the study of aeronautical history—briefly, “the evolution of flight”—has not hitherto received more serious attention. In recent years aeronautical science has achieved results which are ultimately destined to affect profoundly civilisation at large, and yet the number of those interested in the earlier history of the science still remains strangely limited. In England, at least, scholarship has played no part in its elucidation, and such compilations as have appeared have been largely drawn from secondhand and usually unreliable authorities. Two reasons may be offered for this apparent neglect. Until times within memory aeronautical projects were commonly regarded as the work of mistaken enthusiasts or cranks and dismissed accordingly; and since the days of achievement men have been too fully occupied in doing to find time or inclination for the study of earlier and apparently fruitless periods. On that account the majority of readers of this journal, concerned mainly with matters technical, may find the work under review less interesting than it will be to collectors of the raw materials of aeronautical history.

France, it is true, has been somewhat better served, and fittingly so, having regard to the high place she holds in aeronautical invention and development. Moreover, it may be hoped that the small but scholarly work of Giuseppe Boffito, “Il Volo in Italia,” published in Florence last year, is significant of a more serious attitude now becoming apparent.

In any case the appearance of this handsome volume is welcome, and its distinguished authors deserve praise as much for the admirable spirit which prompted it as for the enterprise and skill displayed in its production. The publication was conceived by that veteran in aeronautics, Comte de la Vaulx, as a tribute to M. F.-L. Bruel, whose great work, “Histoire Aéronautique par les Monuments,” published in 1909, it is designed to supplement. Following the lines of Bruel’s earlier work, the present volume consists of over 100 excellent reproductions, wholly in facsimile and many in colour, of engravings, drawings, portraits, autographs, and so forth, varying of course both in interest and historic importance, but accompanied by ample descriptive notes. Rather more than half the plates illustrate the earlier phases of ballooning, the endeavours to construct dirigibles and some forerunners of mechanical flight, while the last forty deal with the period of conquest, “Le Triomphe de l’Aéronautique,” as well as a few connected with the Great War. Space forbids more than brief mention of a few at random.

Pilâtre de Rozier’s first free ascent—a wondrous achievement in its time—is seen in a contemporary drawing by Desrais, while another excellent drawing depicts the ascent of the huge “Flesselles” balloon, with Pilâtre portrayed—truly, as one can well believe—balancing himself on the gallery. The plate of Garnerin’s parachute recalls that his first descent was regarded by Wilbur Wright as the most courageous act in aeronautical history—an opinion expressed long ago by Sir Sydney Smith, who went to see Garnerin’s descent in London in order “to shake hands with a brave man.” The engraving of the rescue of Zambeccari—the unsuccessful rival of Lunardi and a remarkable pioneer of ballooning—is likewise associated with a modern pioneer, for the youthful imagination of Lilienthal was first quickened to an interest in aeronautics on reading the adventures of Zambeccari. The fine portrait of Charles Green—a coloured design of

his famous "Nassau Balloon" forms a decorative wrapper for the book—confirms an impression of the sturdy character of this life-long exponent of the free balloon, though incidentally it is not a fact (as the text states) that his career was "without accident." He had several notable escapes from imminent death when his admirable judgment and self-control alone saved him. The crude poster of Gale's balloon with an upper and lower car connected by a rope ladder, is less interesting than the fact that Coxwell afterwards used it in Berlin (about 1848) to demonstrate that "aerial torpedoes" could be effectively dropped from a balloon. The countless early projects and endeavours in the direction of "dirigibles" are illustrated in several plates—notably the "Eagle," designed by Count Lennox in 1832, which it is interesting to compare with his later and even less successful London venture. Of greater importance are the designs of Pierre Julien, 1851—the notable streamline form of his "Précurseur" justifies the name—Giffard's steam-driven dirigible of 1852, and the famous "La France" of Renard and Krebs; though one might wish that the latter plate depicted less landscape and more dirigible.

Of "heavier-than-air" design there is naturally little in the pre-conquest period. The large picturesque lithograph of Henson's "Aerial"—which, as a print, is better in colours—gives rise to a reflection as to how far Henson was indebted to Cayley, and from that to the more certain conviction that the significance of Cayley's ideas and calculations on dirigibles, and his experiments with gliders in relation to mechanical flight have not yet been justly appraised. In any case it is misleading to refer to Henson as the "constructeur," for the "Aerial" was never constructed save on model scale. A more controversial issue is raised by the plan of Ader's "Avion," though Count de la Vaulx, in his introduction, definitely claims for his compatriot "la gloire impérissable d'avoir, le premier, réalisé le vol humain." Nor is it wholly profitable to debate such claims—honour in full measure may justly be allowed to the unsuccessful and successful pioneers alike, and we may be satisfied to believe that the latter would be the first to accord it in full measure to their forerunners. The later plates in the periods of "Conquest" and "War" do not call for comment—the names of Lilienthal, Ferber, Latham, Wilbur Wright, Pégoud and Guynemer, are in themselves splendidly sufficient.

As to the text, it would be ungracious to criticise the Count de la Vaulx's "Introduction"—if as to matter it is neither more nor less adequate than many similar pieces of writing, it is certainly inspired with a fine spirit of enthusiasm and generous appreciation. But one may regret that it is marred even by such small errors as the reference to "Pierre Wilkins" (the hero of Paltock's charming romance) as an author, or the repeated mis-spelling of the name of Sir George Cayley. The *format* of the volume has only been equalled in Bruel's own book, possessors of which may wish that a uniform size had been adopted. Moreover, users of the present volume as a work of reference will doubtless also wish that some more convenient arrangement of text and plates (the latter being entirely unnumbered) had been followed. Such defects detract, however, but little from the historical value of the book, or from the pleasure it must afford to the fortunate but limited owners of it. Should it serve to inspire some English publisher to undertake a similar enterprise, it will have served a double purpose.

The Internal Combustion Engine. By Major H. E. Wimperis.

The author has provided a useful textbook for students, giving in a small volume a survey of the theoretical and practical problems of internal combustion engines.

He has been particularly successful in putting forward the essential subjects from the various sciences necessary for a clear understanding of the working of the internal combustion engine.

The wide subject covered makes it impossible to go very deeply into all aspects of the problems involved, but references to numerous papers dealing with particular subjects are given.

The book is divided into three approximately equal sections dealing with (1) thermodynamics, (2) gas engines and gas producers, and (3) oil and petrol engines respectively.

In Section I. the laws of gases and the various cycles are explained in a simple manner. A somewhat large proportion of the space is devoted to the researches of various workers on explosions of still gases in closed vessels.

In Section II. descriptions of various types of gas engine, including the gas turbine and the Humphrey pump, and gas producers are given, together with test results of actual plants. A few problems of design, such as balancing, are discussed.

In Section III. various types of oil and petrol engine, carburettors and ignition apparatus are illustrated and described.

Very little space is devoted particularly to engines for aircraft.

In common with many textbooks on engines, very little consideration is given to the methods of the designer in arriving at a solution of his conflicting theoretical and mechanical problems.

A discussion on the art of mechanical design as applied, say, to an aircraft engine would form an interesting addition to the book.

Some excellent examples of exercises for the student are given at the end of each chapter.







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